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The Enthalpies of Combustion and Formation of Ortho- and Parafluorobenzoic Acid

Walter H. Johnson and Edward J. Prosen

Institute for Materials Research, National Bureau of Standards, Washington, DC 20234

(January 17, 1975)

The enthalpies of combustion and formation of one sample of ortho- and two samples of parafluorobenzoic acids have been determined by combustion in an oxygen-bomb calorimeter. The data obtained by other investigators are discussed briefly. The values obtained and their estimated uncertainties are as follows:

	o-Fluorobenzoic acid	*p*-Fluorobenzoic acid I	*p*-Fluorobenzoic acid II
$\Delta Hc°$ (25°C)	−3080.00 ± 1.02 kJ/mol	−3062.97 ± 0.70 kJ/mol	−3063.78 ± 0.80 kJ/mol
$\Delta Hf°$ (25°C)	−568.52 ± 1.10 kJ/mol	−585.56 ± 0.81 kJ/mol	−584.74 ± 0.90 kJ/mol

where $\Delta Hc°$ corresponds to the reaction:

$$C_7H_5O_2F(c) + 7\,O_2(g) + 48\,H_2O(liq) \rightarrow 7\,CO_2(g) + [HF + 50\,H_2O](liq).$$

Key words: Combustion; enthalpy; formation; heat; isomerization; secondary standard.

1. Introduction

Because of the increasing interest in halogen-containing compounds and since certain special techniques must be observed in the combustion calorimetry of these materials, it is important that a secondary standard reference material be made available to all investigators working in this field. Such a substance must have certain characteristics common to most standard reference materials for calorimetry. The material must be stable in moist air as well as under oxygen pressure; it must be essentially non-hydroscopic and have a very low vapor pressure. It must be capable of ignition and burn completely without the need of any auxiliary material to yield well-defined combustion products.

Fluorine compounds in which the fluorine to hydrogen ratio is less than unity burn to give all the fluorine as hydrogen fluoride; where the ratio is greater than unity, significant amounts of carbon tetrafluoride will be formed. There should, therefore, be two reference standards, one of each type. This paper deals only with a proposed standard where all fluorine is converted to hydrogen fluoride.

2. Materials

Benzoic acid

The benzoic acid used for calibration was NBS Standard Reference Material No. 39i for which the heat of combustion under certificate conditions was certified to be 26434 J/g.

Orthofluorobenzoic acid and Parafluorobenzoic acid I

The samples of orthofluorobenzoic acid and parafluorobenzoic acid were obtained from the Thermodynamics Laboratory of the U.S. Bureau of Mines through the courtesy of W. D. Good. The source and purification of these samples have been described [1].[1]

Parafluorobenzoic acid II

This sample was obtained from the J. T. Baker Chemical Company[2] through the NBS Office of

[1] Figures in brackets indicate the literature references at the end of this paper.

[2] Certain commercial products are identified in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the products identified are necessarily the best available for the purpose.

Standard Reference Materials. This material was designated as an Ultrex Product, Commodity No. 4979, Lot No. UHC 314. A certificate of analysis furnished with the sample indicated a minimum purity of 99.9 percent.

All samples were used as received with no further treatment.

Oxygen

The oxygen used in these experiments was a commercial grade of stated 99.9 mol percent purity, further purified by passing over copper oxide at 500 °C and through absorbers to remove carbon dioxide and water. The small amounts of nitrogen and other non-combustible impurities would not be expected to have any significant effects.

3. Apparatus and Procedure

The adiabatic rotating-bomb calorimeter, the automatic shield-temperature controls, the method of sample ignition and the system for measurement of calorimeter temperature will be described in a forthcoming paper [2]; a partial description is given in a report by Armstrong and Johnson [3].

The sample was pressed into a pellet and weighed into a platinum crucible; the weights were corrected to weights in vacuum by the application of buoyancy corrections obtained from air-density measurements. The crucible was supported in the bomb such that the sample was in contact with a 2-cm length of 0.075-mm diam platinum wire connected between the bomb electrodes. A carefully measured quantity of water (3.000 cm^3) was placed in the bomb which was then sealed, flushed with 1 dm^3 of oxygen and filled with 31.62 atm (3.203 MPa) with high-purity oxygen. The bomb was placed in the calorimeter, the calorimeter jacket was evacuated, the adiabatic temperature controls placed in operation and the bomb was heated electrically to approximately 24.98 °C. The calorimeter was left overnight with the pumps and temperature controls in operation.

On the following morning, calorimeter temperatures were observed at intervals of a few minutes during a 40-min initial period. Because of the heating effect of the 5-mA current through the platinum resistance thermometer, a continuous rise in temperature of approximately 0.001 °C/hr was observed. The sample was then ignited and the bomb rotated to obtain a homogeneous bomb solution. After about 20-min thermal equilibrium was approximately achieved and calorimeter temperatures were observed at intervals of a few minutes during a 40-min final period. The observed rise in temperature was determined by extrapolating the time-temperature curves for the rating periods to the time of ignition.

The bomb was removed from the calorimeter and the gaseous contents passed successively through a drying tube and a weighed absorption tube to collect the CO_2. The absorption tube was flushed with dry hydrogen before the initial weighing and after the CO_2-absorption to reduce the displacement correction. Weighing of the absorption tube was made against a tare, consisting of a similar but slightly heavier tube in order to maintain a constant load on the balance. This also tended to reduce possible errors which may be introduced by changes in humidity and atmospheric pressure between the weighings.

The bomb was then opened and the liquid contents transferred to a weighed polyethylene bottle. A weighed aliquot was placed in a polyethylene titration flask containing a plastic-coated, magnetic stirring bar, and CO_2-free air was bubbled through the solution to remove most of the dissolved carbon dioxide. Slightly less than the theoretical quantity of standard alkali was then added, the combination glass-calomel electrode was introduced and the titration was completed using a pH-meter.

A second aliquot was taken for the determination of nitric acid, which was made by a modified micro-Kjeldahl procedure [4]. The modification consisted of substituting an infrared lamp for the internal heating coil.

In order to determine any variation in sample weight due to adsorbed moisture, weighed samples of each compound and of benzoic acid 39i were dissolved in 10 cm^3 of ethanol, the solution diluted to 30 cm^3, and titrated with standard alkali, using a pH-meter. This was done to determine the carboxyl content of each sample.

The procedure for the benzoic calibration experiments was the same as for the fluoro-benzoic acid combustion experiments except that the quantity of water initially placed in the bomb was 0.3 cm^3. Since no temperature effect was observed upon rotation of the bomb, the rotation was usually omitted in those experiments.

4. Results and Calculations

The auxiliary values used in the calculations are as follows:

	Density $g \cdot cm^{-1}$	Cp $J \cdot g^{-1} \cdot K^{-1}$	$\left(\frac{-\partial U}{\partial P}\right)_T$ $J \cdot g^{-1} \cdot atm^{-1}$
Benzoic acid	1.320	1.21	0.012
o-Fluorobenzoic acid	1.460	1.13	.012
p-Fluorobenzoic acid	1.479	1.13	.012

The heats of formation and dilution of aqueous hydrofluoric acid were taken from Johnson, Smith and Hubbard [5]. The apparent molal heat capacity of HF in aqueous solution were taken from Parker [6]. Other auxiliary data were taken from Wagman et al. [7].

The unit of energy has been taken as the joule; for conversion from data given in the conventional thermochemical calorie, one calorie is equivalent to 4.184 J.

The standard calorimeter system was taken to include the empty bomb with all internal platinum

parts except the crucible. The results of the benzoic acid calibration experiments are given in tables 1 and 2 for observed temperature increments of 1 K and 3 K respectively. The certified value of ΔUc for benzoic acid (the change in internal energy for the bomb process) under certificate conditions was −26434 $J \cdot g^{-1}$; this reduces to −26412.35 and −26410.36 $J \cdot g^{-1}$ for $\Delta Uc°$ at 26 °C and 28 °C respectively.

The headings, in the order in which they appear in the tables, are described as follows:

EEE-Std, the effective energy equivalent of the standard, empty calorimeter at the standard mean temperature of the experiment;

Cv-cont(i), the heat capacity of the initial bomb contents, including the sample, crucible, water and oxygen;

Corr to tm, a correction to the heat capacity of the initial calorimetric system for the deviation of the actual mean temperature of the experiment from the standard mean temperature;

Corr-parts, a correction for alterations to the system during the series of experiments;

EEE-actual, the effective energy equivalent of the actual system at the actual mean temperature of the experiment;

Temp. rise, the observed increase in temperature of the system following ignition of the sample;

Q-total, the total quantity of energy evolved obtained as minus the product of EEE-actual and the temperature rise;

q-ign, the electrical energy added to the system to ignite the sample;

q-decomp HNO_3, the calculated quantity of energy required to decompose any nitric acid, formed in the combustion process, into nitrogen, oxygen, and water;

q-WC, the Washburn Correction [8, 9] applied to convert all reactants and products to their respective standard states at the actual final temperature;

q-corr to std t_f, a correction applied for deviation of the actual final temperature from the selected standard final temperature;

Q-std react, the energy evolved by the reaction with products and reactants in their respective standard states at the selected final temperature obtained as *Q*-total + Σ*q*;

m_s, the mass of sample

$\Delta Uc°$, the energy evolved by the standard reaction at the standard final temperature in $J \cdot g^{-1}$, obtained as *Q*-std react divided by m_s.

All computations were performed by means of a computer program originally prepared by G. H. Shomate, U.S. Naval Ordnance Test Station, China Lake, California and later revised to include fluorine compounds by G. T. Armstrong and E. J. Prosen of this Bureau, according to the method of Hubbard, Scott, and Waddington [9]. An iterative process was used for the calibration experiments whereby EEE-std was calculated from $\Delta Uc°$ for benzoic acid. The values in the tables were taken and rounded from the computer print-out; for this reason the computed values which are more exact may differ slightly from those given in the tables.

Two series of calibration experiments were carried out because of the time lapse between the series. However, the resulting energy equivalent was very near the calculated value obtained by taking the temperature coefficient of EEE-std as 1.8 $J \cdot K^{-1}$ [2].

The results of the fluorobenzoic acid combustion experiments are given in tables 3, 4, and 5. The values obtained correspond to the reaction:

$$C_7H_5O_2F(c) + 7\,O_2(g) + 48\,H_2O(liq) \rightarrow 7\,CO_2 + [HF + 50\,H_2O](liq). \quad (1)$$

The average results of the analytical experiments in percentages of the calculated theoretical values are as follows:

	H^+	CO_2	HF
Benzoic acid	100.00	100.03	
o-Fluorobenzoic acid	99.98	99.98	98.47
p-Fluorobenzoic acid I	99.98	99.94	98.47
p-Fluorobenzoic acid II	100.00	99.92	98.52

TABLE 1. *Calibration experiments for a temperature rise of 1 K*

Expt. No.	232	235	238	239	240	241
EEE-Std, (25.5°C) J/K	2514.17	2513.74	2513.84	2513.66	2514.01	2513.61
Cv-cont(i) J/K	4.58	4.60	4.57	4.56	4.58	4.57
Corr to tm J/K	0.09	0.12	0.07	0.11	0.11	0.10
Corr-parts J/K	0.00	0.00	0.00	0.00	0.00	0.00
EEE-actual J/K	2518.84	2518.45	2518.49	2518.32	2518.69	2518.29
Temp rise K	1.092830	1.125784	1.071099	1.110064	1.094375	1.105424
Q-total J	−2752.66	−2835.23	−2697.55	−2795.50	−2756.39	−2783.78
q-ign J	0.94	1.04	1.03	1.05	1.19	1.05
q-decomp HNO_3 J	0.16	0.20	0.32	0.15	0.17	0.23
q-WC J	1.99	2.06	1.95	2.01	2.00	2.01
q-corr to 26°C J	−0.01	−0.02	−0.01	−0.01	−0.01	−0.01
Q-std react J	−2749.58	−2831.95	−2694.26	−2792.30	−2753.06	−2780.49
m_s g	0.104102	0.107221	0.102007	0.105719	0.104234	0.105272
$\Delta Uc°$(26°C) J/g	−26412.35	−26412.35	−26412.35	−26412.35	−26412.35	−26412.35
Mean, EEE-Std J/K	2513.84					
sdm J/K	0.088					

TABLE 2. *Calibration experiments for a temperature rise of 3 K*

Expt. No.	287	288	289	293	294
EEE-Std (26.5)....J/K...	2515.32	2515.80	2515.55	2515.66	2515.86
Cv-cont(i)....J/K...	4.83	4.85	5.83	4.84	4.84
Corr to tm....J/K...	0.14	0.13	0.14	0.16	0.14
Corr-parts....J/K...	0.00	0.00	0.00	0.00	0.00
EEE-actual....J/K...	2520.29	2520.78	2520.52	2520.66	2520.84
Temp rise....K...	3.160217	3.154736	3.161699	3.172728	3.148872
Q-total....J...	−7964.66	−7952.40	−7969.13	−7997.36	−7937.80
q.ign....J...	0.75	0.94	1.01	1.02	0.86
q-decomp HNO_3....J...	0.38	0.52	0.57	0.84	1.64
q-WC....J...	6.28	6.32	6.30	6.33	6.28
q-corr to 28°C....J...	−0.06	−0.05	−0.06	−0.06	−0.05
Q-std react....J...	−7957.30	−7944.68	−7961.31	−7989.23	−7929.06
m_s....g...	0.301295	0.300817	0.301447	0.302504	0.300225
$\Delta Uc°$(28°C)....J/g..	−26410.36	−26410.36	−26410.36	−26410.36	−26410.36
Mean, EEE-Std. ....J/K...	2515.63				
sdm....J/K...	0.096				

TABLE 3. *Results of calorimetric combustion experiments on o-fluorobenzoic acid*

Expt. No.	224	227	228	233	239	242
EEE-Std (25.5°C)....J/K...	2513.84	2513.84	2513.84	2513.84	2513.84	2513.84
Cv-cont(i)....J/K...	15.75	15.74	15.75	15.74	15.72	15.73
Corr to tm....J/K...	0.19	0.07	0.08	0.13	0.10	0.11
Corr-parts....J/K...	−0.20	−0.20	−0.20	0.00	0.00	0.00
EEE-actual....J/K...	2529.58	2529.45	2529.47	2529.71	2529.66	2529.68
Temp rise....K.....	1.199415	1.059017	1.093357	1.139922	1.096094	1.119318
Q-total....J.....	−3034.02	−2678.72	−2765.61	−2883.67	−2772.75	−2831.52
q-ign....J.....	1.01	0.99	0.97	1.06	1.13	1.06
q-decomp HNO_3....J.....	0.66	0.93	1.18	0.00	0.63	0.47
q-WC....J.....	4.91	4.34	4.48	4.67	4.48	4.58
q-corr to 26°C....J.....	−0.02	−0.01	−0.01	−0.01	−0.01	−0.01
Q-std react....J.....	−3027.46	−2672.46	−2758.99	−2877.95	−2766.52	−2825.42
m_s....g.....	0.137671	0.121621	0.125550	0.130899	0.125816	0.128564
$\Delta Uc°$(26°C)....J/g...	−21990.52	−21973.68	−21975.17	−21986.05	−21988.58	−21976.73
Mean....J/g...	−21981.97					
sdm....J/g...	2.99					

TABLE 4. *Results of the calorimetric combustion experiments on p-fluorobenzoic acid I*

Expt. No.	225	229	230	231	234	237
EEE-Std (25.5°C)....J/K...	2513.84	2513.84	2513.84	2513.84	2513.84	2513.84
Cv-cont(i)....J/K...	15.63	15.76	15.74	15.74	15.73	15.73
Corr to tm....J/K...	0.03	0.14	0.06	0.10	0.04	0.08
Corr-parts....J/K...	−0.20	−0.20	−0.20	0.00	0.00	0.00
EEE-actual....J/K...	2529.30	2529.54	2529.44	2529.68	2529.61	2529.65
Temp. rise....K.....	1.029023	1.133475	1.070583	1.121024	1.034615	1.075966
Q-total....J.....	−2602.71	−2867.17	−2707.98	−2835.84	−2617.18	−2721.82
q-ign....J.....	1.06	0.99	1.04	1.06	1.21	1.02
q-decomp HNO_3....J.....	0.59	0.37	0.37	0.37	0.37	0.59
q-WC....J.....	4.19	4.68	4.42	4.62	4.27	4.44
q-corr to 26°C....J.....	0.00	−0.01	−0.01	−0.01	0.00	−0.01
Q-std react....J.....	−2596.87	−2861.14	−2702.16	−2829.81	−2611.33	−2715.78
m_s....g.....	0.118809	0.130880	0.123594	0.129481	0.119430	0.124236
$\Delta Uc°$(26°C)....J/g...	−21857.61	−21860.83	−21863.12	−21855.09	−21864.95	−21859.88
Mean....J/g...	−21860.25					
sdm....J/g...	1.47					

TABLE 5. *Results of the calorimetric combustion experiments on p-fluorobenzoic acid II*

Expt. No.	284	285	286	290	291	295
EEE-Std, (26.5°C) ....J/K...	2515.63	2515.63	2515.63	2515.63	2515.63	2515.63
Cv-cont(i) ....J/K...	16.03	16.02	16.02	16.00	16.01	15.98
Corr to tm ....J/K...	0.11	0.09	0.10	0.07	0.06	−0.23
Corr-parts ....J/K...	−0.03	−0.03	−0.03	0.00	0.00	0.00
EEE-actual ....J/K...	2531.74	2531.71	2531.72	2531.70	2531.70	2531.38
Temp rise ....K.....	3.129386	3.102385	3.122565	3.057100	3.070654	2.754931
Q-total ....J.....	−7922.79	−7854.34	−7905.46	−7739.66	−7773.97	−6973.78
q-ign ....J.....	0.91	0.96	0.92	0.97	0.95	1.18
q-decomp HNO_3 ....J.....	1.11	0.70	0.82	0.48	0.78	0.78
q-WC ....J.....	12.65	12.53	12.62	12.32	12.40	11.12
q-corr to 28°C ....J.....	−0.03	−0.02	−0.03	−0.01	−0.02	0.05
Q-std react ....J.....	−7908.15	−7840.17	−7891.13	−7725.90	−7759.86	−6960.65
m_s ....g.....	0.361699	0.358428	0.360981	0.353367	0.354923	0.318311
$\Delta Uc°$(28°C) ....J/g ...	−21863.90	−21873.76	−21860.23	−21863.67	−21863.52	−21867.44
Mean ....J/g ...	−21865.42					
sdm ....J/g ...	1.91					

The values obtained for HF appear to be low; the discrepancy, however, may be due to a systematic error in determination of the quantity of nitric acid by the Kjeldahl reduction process which was less precise. In the calculation of the results the conversion of fluorine to hydrofluoric acid was taken to be stoichiometric and the excess acid was taken as nitric acid.

The results of this investigation corresponding to reaction (1) are summarized as follows:

5. Comparison With the Results of Prior Investigations

Good, Scott, and Waddington performed eight combustion experiments on each of the three monofluorobenzoic acids [1]. We have corrected their values to correspond to the 1971 Table of International Atomic Weights [10]. Cox, Gundry, and Head [11] performed five combustion experiments on *p*-fluoro-

TABLE 6. *Summary of the experimental and derived values*

	o-Fluorobenzoic acid kJ/mol	*p*-Fluorobenzoic acid I kJ/mol	*p*-Fluorobenzoic acid II kJ/mol
$\Delta Hc°$(25°C)	−3080.00 ± 1.02	−3062.97 ± 0.70	−3063.78 ± 0.80
$\Delta Hf°$(25°C)	−568.52 ± 1.10	−585.56 ± 0.81	−584.74 ± 0.90

The uncertainties assigned to the values for $\Delta Hc°$ were obtained by combining (square root of sum of squares) 2 sdm (in percent) for the calibration experiments, 2 sdm (in percent) for the combustion experiments, 0.01 percent for the uncertainty in the certified value for benzoic acid, 0.01 percent for the possible effects of organic impurities in the sample, 0.01 percent for the uncertainty in the heat of dilution of hydrofluoric acid and reasonable estimates of all other known sources of error. The uncertainties assigned to the values for $\Delta Hf°$ were obtained by combining the uncertainty in $\Delta Hc°$ with estimated uncertainties of 0.01 percent in the accepted values for the heats of formation of gaseous carbon dioxide and liquid water and of 0.1 percent in the heat of formation of aqueous hydrofluoric acid.

benzoic acid; we have corrected their value for the changes in atomic weights and to correspond to reaction (1) using the data of Johnson, Smith, and Hubbard [5]. We have made no attempt to correct the values of Swarts [12] because of insufficient experimental data. Good, Scott, and Waddington [1] have discussed this early work of Swarts in some detail and have concluded that his values are in error by 0.5 to 1.0 percent.

A comparison of the results obtained by the various investigators is given in table 7.

TABLE 7. *Comparison of the results with those of other investigators*

	o-Fluorobenzoic acid $\Delta Hc°$(25°C), J/g	*m*-Fluorobenzoic acid $\Delta Hc°$(25°C), J/g	*p*-Fluorobenzoic acid $\Delta Hc°$(25°C), J/g
Good, Scott, Waddington [1]	−21986.9 ± 10.7	−21883.6 ± 6.0	−21850.5 ± 8.7
Cox, Gundry, and Head [11]			−21863.2 ± 6.3
Swarts [12]	−22113.	−22037	−22099
This investigation	−21981.8 ± 7.3		−21865.4 ± 5.6

6. Discussion

Certain impurities may cause serious analytical problems. In another sample of *o*-fluorobenzoic acid we found the purity to be 99.90 percent on the basis of

carboxyl titration, 100.2 percent on the basis of carbon dioxide, and 99.9+ percent by melting point determination. The heat of combustion was −3079.74 kJ/mol based upon the mass of sample and assuming no significant impurity. However, analyses of the bomb solution yielded only 83.3 percent of the theoretical quantity of HF. A careful study of the data indicated the presence of salicylic acid which was later verified by a mass-spectrometric analysis. Salicylic acid forms a mixed crystal with *o*-fluorobenzoic acid and, having the carboxyl group and very similar values for the weight-percentage of carbon, molecular weight, and heat of combustion, it can easily pass undetected. It is imperative, therefore, that a careful analysis of the resulting bomb solution be made and when a significant discrepancy occurs a mass-spectrometric study is in order.

We believe that *p*-fluorobenzoic acid is a completely satisfactory material for a secondary thermochemical standard for use in the combustion calorimetry of fluorine compounds. The material is non-volatile, non-hygroscopic, stable in the presence of oxygen, may be ignited easily and burns completely without the need for an auxiliary substance.

This work was supported in part by the Office of Standard Reference Materials of the National Bureau of Standards.

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The Enthalpies of Combustion and Formation of Acetanilide and Urea

Walter H. Johnson

Institute for Materials Research, National Bureau of Standards, Washington, D.C. 20234

(January 17, 1975)

The enthalpies of combustion of acetanilide and urea have been determined in an oxygen-bomb calorimeter. The following values and their estimated uncertainties were obtained.

	Acetanilide	Urea
$\Delta Hc°(25°C)$	-4224.88 ± 0.93 kJ/mol	-631.78 ± 0.16 kJ/mol
$\Delta Hf°(25°C)$	-209.40 ± 1.00 kJ/mol	-333.39 ± 0.17 kJ/mol

A comparison with previously reported data is given.

Key words: Combustion; enthalpy; formation; heat; secondary standard; thermochemical standard.

1. Introduction

There is need for a standard reference material for use in the combustion calorimetry of nitrogen-containing compounds. These compounds may be divided into two main classes: (1) those containing relatively small amounts of nitrogen which may be burned without an auxiliary material and (2) those containing larger amounts which require an auxiliary material for ignition and complete combustion. Acetanilide, which contains 10.4 wt percent nitrogen, has been proposed as a secondary standard for compounds which do not require any auxiliary material. It is available in high purity, is nonhygroscopic, has a very low vapor pressure, can be pressed into reasonably good pellets, can be ignited with any type of fuse and burns completely without an auxiliary substance. It is available through the Office of Standard Reference Materials (OSRM) as a microanalytical standard for nitrogen compounds.

Urea, which contains 46.6 wt percent nitrogen, has been proposed as a secondary standard for materials containing larger amounts of nitrogen. Like acetanilide, it appears to have the physical characteristics of a good secondary reference standard. It is available as an analytical standard for clinical laboratories through the Office of Standard Reference Materials.

2. Materials

Acetanilide

The sample was obtained from the OSRM as SRM 141B. The certificate gave the purity as 99.99 mol percent. It was stored in air at room temperature and was burned as received with no attempts at further purification.

Urea

The sample was obtained from the OSRM as SRM 912. The certificate of analyses gave the purity as 99.7 weight percent with impurities being moisture, 0.18 percent; biuret, 0.07 percent; ash, 0.002 percent, and insoluble matter, 0.002 percent. We believed that the moisture content was significantly less than the certificate value because repeated drying at 100 °C gave a constant loss of weight, approximately 0.012 percent/h, which must be attributed to volatilization of the sample. A redetermination of the moisture content of the sample by S. Margolis of this Bureau found 0.02 wt percent. It appears that some loss of moisture occurred after the initial determination.

3. Apparatus and Procedure

The adiabatic rotating-bomb calorimeter, the adiabatic shield-controls and the method of temperature measurement will be described in a forth-coming publication [1]. A partial description is given in a report by Armstrong and Johnson [2].

The calorimeter was calibrated by a series of combustion experiments using benzoic acid, SRM 39i. In each experiment a sample of approximately 0.3 g was pressed into a pellet, weighed into a platinum crucible and placed in the bomb which contained 0.3 cm^3 of water. The bomb was sealed, filled with 30 atm (3.040 MPa) of oxygen and the oxygen was released slowly; the bomb was refilled to 31.62 atm (3.204 MPa), and transferred to the calorimeter. The temperature of filling was observed, the calorimeter jacket was evacuated, the bomb was heated electrically to 24.98 °C and the sytem was left overnight with the pumps and the adiabatic temperature controls in operation.

On the following day, calorimeter temperatures were observed at intervals during an initial rating period and the sample was ignited by means of an electrical current through a platinum wire fuse which was in contact with the sample. Approximately 3 min after ignition the bomb was rotated to obtain a homogeneous bomb solution. After about 20 min thermal equilibrium was established and calorimeter temperatures were observed at intervals during the final rating period. Because of the heating effect of the 5 mA current through the platinum resistance thermometer, a steady rise in the temperature of the calorimeter (approximately 0.001 K/h) was observed during the rating periods. The temperature rise due to the overall bomb process was obtained by extrapolation of the time-temperature curves to the actual time of ignition.

The bomb was removed from the calorimeter, the gaseous contents were released, the bomb was opened and the bomb solution transferred to a beaker. The solution was boiled to remove traces of carbon dioxide, cooled and titrated with standard alkali using a pH-meter to determine the quantity of nitric acid. In some cases the solution was analyzed for nitrous acid but the quantities observed were completely negligible.

The procedure with acetanilide was the same as that for benzoic acid except that the quantity of water initially placed in the bomb was 3.000 cm^3. The procedure for the urea experiments was the same as for acetanilide except that a small pellet of benzoic acid, was added. The pellets of urea were made in a special press which produced a cavity 3.5 mm in diameter and 1.5 mm in depth in the top of the pellet. Another press was used to make a pellet of benzoic acid which was 3 mm in diameter and about 1 mm thick. The urea pellet was weighed into the crucible, the benzoic acid pellet was dropped into the cavity and total weight was observed. The platinum fuse wire was adjusted so that it was in contact with the benzoic acid pellet.

4. Results and Calculations

The unit of energy is the joule; for conversion to the conventional thermochemical calorie, 1 $cal_{th} = 4.184$ J. The certified value for benzoic acid, SRM 39i, under certificate conditions is 26434 ± 3 J/g. This reduces to $\Delta U_c^\circ(28°C) = -26410.36 \pm 3$ J/g. The following values have been used in the calculations.

	density, $g \cdot cm^{-3}$	Cp, $J \cdot g^{-1} K^{-1}$	$\left(\frac{\partial U}{\partial P}\right)_t$, $J \cdot g^{-1} \cdot atm^{-1}$
Benzoic acid	1.320	1.21	−0.0126
Acetanilide	1.22	1.39	−0.0069
Urea	1.21	1.55	−0.005

The heat of decomposition of the nitric acid in the bomb solution into nitrogen, oxygen, and water has been taken as 59.7 kJ/mol. The auxiliary data was taken from Wagman et al., NBS Tech. Note 270–3 [3]. All values are based on the 1971 Table of International Atomic Weights [4]. All calculations were performed by computer.[1]

The results of the benzoic acid calibration experiments are given in table 1. The headings, in the order in which they appear in the tables, are described as follows:

EEE-Std, the effective energy equivalent of the standard, empty calorimeter at the standard mean temperature of the experiment.

Cv-cont(i), the heat capacity of the initial bomb contents, including the sample, crucible, water and oxygen;

Corr to tm, a correction to the heat capacity of the initial system for deviation of the actual mean temperature of the experiment from the standard mean temperature;

Corr-parts, a correction for alterations to the system during the series of experiments;

EEE-actual, the effective energy equivalent of the actual system at the actual mean temperature of the experiment;

Temp. rise, the observed increase in temperature of the system following ignition of the sample;

Q-total, the total quantity of energy evolved obtained as minus the product of the temperature rise and EEE-actual;

q-ign, the electrical energy added to the system to ignite the sample;

q-decomp HNO_3, the calculated quantity of energy required to decompose any nitric acid, formed in the combustion process, into nitrogen, oxygen, and water;

q-WC, the Washburn Correction [5, 6] applied to convert all reactants and products to their respective standard states at the actual final temperature;

q-corr to std t_f, a correction applied for deviation of the actual final temperature from the selected standard final temperature;

Q-std react, the energy evolved by the reaction with products and reactants in their respective

[1] The computer program used was originally prepared by C. H. Shomate of the Naval Ordinance Test Station, China Lake, California, and later revised by G. T. Armstrong and E. J. Prosen of this Bureau, according to the method of Hubbard, Scott, and Waddington [5].

standard states at the selected final temperature obtained as the sum of Q-total and Σq.

m_s, the mass of sample

$\Delta Uc°$, the energy evolved by the standard reaction at the standard final temperature in $J \cdot g^{-1}$.

The results have been taken directly from the computer print-out and have been rounded for convenience; for this reason small differences may result by calculation from the tabulated data.

The results of the values for the effective energy equivalent from the benzoic acid calibration experiments were determined by an iterative procedure from the mass of sample. The standard calorimeter included the empty bomb and all internal platinum parts except the crucible.

The results of the seven experiments on acetanilide are given in table 2 and correspond to the reaction:

$$C_8H_9ON(c) + 9.75\ O_2(g) \rightarrow 8\ CO_2(g) + 4.5\ H_2O\ (liq) + 0.5\ N_2(g)$$

$$\Delta Uc°(28°C) = -31230.00\ J/g,\ sdm = \pm 1.72\ J/g.$$

The results of the seven experiments on urea are given in table 3 and correspond to the reaction:

$$CH_4ON_2(c) + 1.5\ O_2(g) \rightarrow CO_2(g) + 2H_2O(liq) + N_2(g)$$

$$\Delta Uc°(28°C) = -10536.56\ J/g,\ sdm = \pm 0.30\ J/g.$$

The results of this investigation and the values derived from the results are summarized in table 4. The uncertainties assigned to $\Delta Uc°$ and $\Delta Hc°$ were obtained by combining (square root of the sum of squares) 2 sdm (in %) for the calibration experiments, 2 sdm (in %) for the combustion experiments, 0.01 percent for the possible effect of organic impurities in the sample, 0.01 percent for the uncertainty in the certified value for benzoic acid, and reasonable estimates of all other sources of error. The uncertainty assigned to $\Delta Hf°$ was obtained by combining the uncertainty of $\Delta Hc°$ with estimated uncertainties of 0.01 percent in the values taken for the heats of formation of carbon dioxide and water [3].

A comparison of the results obtained in this investigation with previously reported values for acetanilide and urea is given in table 5. Wadsö [6] calculated the enthalpy of combustion of acetanilide as −1009.5 kcal/mol (−4223.75 kJ/mol) from measurements of the heat of hydrolysis of acetic anhydride and the heat of reaction of acetic anhydride with aniline. Månsson and Sunner [8] measured the enthalpy of combustion of urea using paraffin oil as an auxiliary and obtained 150.89 ± 0.02 kcal/mol. Their data agrees well with that obtained by Huffman [9] who used a similar auxiliary material and obtained − 150.99 ± 0.04 kcal/mol.

In view of the good agreement between the results it would appear that both of these materials would be quite satisfactory as secondary thermochemical standards for the calorimetry of nitrogen-containing compounds.

TABLE 1. *Results of the benzoic acid calibration experiments*

Expt. No.	390	396	426	427	436	445
EEE-Std, (26°5°C)....J·K⁻¹...	2519.28	2519.39	2518.49	2518.88	2519.50	2518.97
Cv-cont(i)....J·K⁻¹...	4.75	4.72	4.86	4.82	4.87	4.75
Corr to tm....J·K⁻¹...	0.13	0.04	0.08	0.14	0.19	0.16
Corr-parts....J·K⁻¹...	− 0.23	− 0.23	0.00	0.00	0.00	0.00
EEE-actual....J·K⁻¹...	2523.93	2523.92	2523.43	2523.84	2524.56	2523.88
Temp rise....K.....	3.137830	3.059233	3.105295	3.177676	3.203383	3.181825
Q-total....J.....	− 7919.66	− 7721.25	− 7836.00	− 8019.96	− 8087.12	− 8030.54
q-ign....J.....	0.89	1.05	0.82	0.79	0.94	1.06
q-decomp HNO_3....J.....	0.87	1.01	0.55	0.29	0.12	2.30
q-WC....J.....	6.30	6.08	6.19	6.40	6.46	6.38
q-corr to 28°C....J.....	− 0.05	− 0.02	− 0.03	− 0.06	− 0.07	− 0.06
Q-std react....J.....	− 7911.64	− 7713.13	− 7828.48	− 8012.53	− 8079.68	− 8020.86
m_s....g.....	.299566	.292050	.296417	.303386	.305928	.303701
$\Delta Uc°$(28°C)....J·g⁻¹...	− 26410.36	− 26410.36	− 26410.36	− 26410.36	− 26410.36	− 26410.36
Mean, EEE-Std....J·K⁻¹...	2519.09					
sdm....J·K⁻¹...	0.15					

TABLE 2. *Results of the combustion experiments on acetanilide*

Expt. No.	429	437	438	439	440	441	443
EEE-Std ..... J·K^{-1} ...	2519.09	2519.09	2519.09	2519.09	2519.09	2519.09	2519.09
Cv-cont(i) ..... J·K^{-1} ...	4.88	15.99	15.96	15.87	15.97	15.96	15.94
Corr to tm ..... J·K^{-1} ...	0.25	− 0.50	0.22	0.19	0.22	0.19	0.17
Corr-parts ..... J·K^{-1} ...	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EEE-actual ..... J·K^{-1} ...	2524.22	2534.58	2535.27	2535.15	2535.28	2535.24	2535.20
Temp rise ..... K	3.274775	2.455891	3.225777	3.214285	3.256874	3.223884	3.232475
Q-total ..... J	− 8266.25	− 6224.65	− 8178.22	− 8148.70	− 8257.10	− 8173.33	− 8194.96
q-ign ..... J	0.76	1.01	0.91	0.84	0.91	1.06	0.81
q-decomp HNO_3 ..... J	16.01	9.68	16.29	16.72	15.99	16.51	16.30
q-WC ..... J	5.12	6.98	9.25	9.19	9.35	9.24	9.24
q-corr to 28°C ..... J	− 0.10	0.16	− 0.09	− 0.08	− 0.09	− 0.08	− 0.08
Q-std react ..... J	− 8244.46	− 6206.82	− 8151.85	− 8122.04	− 8230.94	− 8146.60	− 8168.69
m_s ..... g	0.263977	0.198784	0.261033	0.260104	0.263557	0.260851	0.261497
$\Delta Uc°$(28°C) ..... J·g^{-1} ...	− 31231.70	− 31223.87	− 31229.14	− 31226.08	− 31230.18	− 31230.81	− 31238.19
Mean, $\Delta Uc°$(28°C) ..... J·g^{-1} ...	− 31230.00						
sdm ..... J·g^{-1} ...	1.72						

TABLE 3. *Results of the combustion experiments on urea*

Expt. No.	430	431	432	433	434	435	444
EEE-Std ..... J·K^{-1} ...	2519.09	2519.09	2519.09	2519.09	2519.09	2519.09	2519.09
Cv-cont(i) ..... J·K^{-1} ...	16.87	16.81	16.79	16.80	16.80	16.83	16.79
Corr to tm ..... J·K^{-1} ...	0.29	0.08	0.04	0.05	0.09	0.15	0.03
Corr-parts ..... J·K^{-1} ...	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EEE-actual ..... J·J^{-1} ...	2536.25	2535.98	2535.92	2535.94	2535.98	2536.07	2535.91
Temp rise ..... K	3.329777	3.093843	3.044748	3.068810	3.110405	3.166079	3.036571
Q-total ..... J	− 8445.15	− 7845.92	− 7721.24	− 7782.32	− 7887.93	− 8029.39	− 7700.47
q-ign ..... J	0.79	0.86	0.92	0.81	0.89	0.81	0.96
q-decomp HNO_3 ..... J	27.21	25.10	25.20	25.29	26.25	24.80	25.01
q-WC ..... J	11.96	11.08	10.87	10.97	11.11	11.37	10.85
q-aux ..... J ...	447.32	411.34	295.78	382.26	434.61	441.32	327.06
q-corr to 28°C ..... J ...	− 0.31	− 0.08	− 0.04	− 0.06	− 0.09	− 0.15	− 0.03
Q-std react ..... J ...	−7958.17	−7397.61	−7388.51	−7363.04	−7415.16	−7551.23	−7336.63
m_s ..... g ...	0.755195	0.702119	0.701249	0.698866	0.703709	0.716609	0.696301
$\Delta Uc°$(28°C) ..... J·g^{-1} ...	−10537.90	−10536.12	−10536.23	−10535.71	−10537.26	−10537.45	−10536.58
Mean, $\Delta Uc°$(28°C) ..... J·g^{-1} ...	−10536.75						
sdm ..... J·g^{-1} ...	0.30						

TABLE 4

	Acetanilide	Urea
$\Delta Uc°$(28°C)	−31230.00 ± 6.87 J/g	−10536.75 ± 2.74 J/g
$\Delta Hc°$(28°C)	−4224.34 ± 0.93 kJ/mol	−631.54 ± 0.16 kJ/mol
$\Delta Hc°$(25°C)	−4224.88 ± 0.93 kJ/mol	−631.78 ± 0.16 kJ/mol
$\Delta Hf°$(25°C)	−209.44 ± 1.00 kJ/mol	−333.39 ± 0.17 kJ/mol

TABLE 5. *Comparison with previously reported values*

	Acetanilide $\Delta Hc°$(25°C), kJ/mol	Urea $\Delta Hc°$(25°C), kJ/mol
Wadsö	−4223.75 [7]	
Månsson and Sunner		−631.33 ± 0.10 [8]
Huffman		−631.75 ± 0.18 [9]
This investigation	−4224.88 ± 0.93	−631.78 ± 0.17

This work was supported, in part, by the Office of Standard Reference Materials of the National Bureau of Standards.

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The Enthalpies of Combustion and Formation of Cholesterol [cholest-5-en-3-ol (3_β)]

Walter H. Johnson

Institute for Materials Research, National Bureau of Standards, Washington, D.C. 20234

(March 6, 1975)

The enthalpy of combustion of cholesterol was measured in an adiabatic, rotating-bomb calorimeter capable of high precision with relatively small samples. The random error for the experimental measurements was 0.006 percent which may be compared with approximately 0.3 percent for prior investigations on this substance. The results obtained for the enthalpy of combustion and the derived enthalpy of formation together with the estimated overall uncertainties are:

$$\Delta Hc°(25℃) = -16524.0 \pm 3.9 \text{ kJ/mol}$$
$$\Delta Hf°(25°C) = -674.8 \pm 4.1 \text{ kJ/mol}$$

The results of prior investigations are discussed briefly.

Key words: Cholesterol; clinical standard; combustion, heat of; enthalpy; formation, heat of; reference material.

1. Introduction

Cholesterol [cholest-5-en-3-ol (3β)] is one of the basic sterols which occurs in all animal tissues and is of great importance to animal life. The thermodynamic properties of this material are, therefore, important in the study of the biochemical processes in which it is involved. It is one of the biomedical chemicals which is certified for purity and offered as a standard reference material (SRM 911a) by the NBS Office of Standard Reference Materials. Since this material is of natural origin it is expected to be essentially free of sterol isomers.

Prior investigations on the enthalpy of combustion of this compound have been subject to relatively large uncertainties which may be due to the difficulty in obtaining a highly purified sample.

2. Materials

Benzoic Acid

The benzoic acid used for calibration of the calorimeter was SRM 39i for which the energy of combustion under certificate conditions was certified to be 26434 J/g. Correction to standard conditions at 28 °C gave $\Delta Uc°(28℃) = -26410.36$ J/g.

Oxygen

High-purity oxygen was used for both calibration and combustion experiments; the main impurities being 3 ppm of nitrogen, 2 ppm of water, and 0.8 ppm of nitrous oxide. The presence of these impurities would not have a significant effect upon the results of this investigation.

Cholesterol, NBS Standard Reference Material 911a.

The results of the analytical procedures are given in the NBS Certificate of Analysis [1][1] and some of these procedures are summarized here for convenience.

The melting point of this material, measured in a sealed tube under vacuum, is 149.0 to 149.4 °C. The specific rotation $[\alpha]_D^{20}$ is -0.700 rad ($-40.1°$) (c, 1; $CHCl_3$). Microchemical analysis found carbon 83.86 ±0.05 and hydrogen 12.00 ± 0.05 weight percent; the theoretical percentages based on $C_{27}H_{46}O$ are 83.87 and 11.99, respectively.

Heating the material at 100 °C and 3 Pa (0.02 torr) resulted in a nearly constant loss in weight of 0.01 percent per hour over a 36 hour period; such a volatilization may be related to degradation and/or sublimation processes. These results appear to eliminate the probability of water as an impurity. The certified purity of this sample is given on the Certificate of Analysis as 99.8±0.1 percent.

[1] Figures in brackets indicate the literature references at the end of this paper.

3. Apparatus and Procedure

The platinum-lined bomb and the adiabatic calorimeter have been described [2]. The volume of the bomb is 98 cm^3.

The sample was stored in a desiccator over magnesium perchlorate and kept at approximately 0 °C. The desiccator was warmed to room temperature before opening. Samples of approximately 0.18 g each were pressed into pellets. The sample was weighed into a platinum crucible which was placed in the bomb so that the pellet was in contact with a 2-cm length of 0.075-mm diam platinum wire connected between the electrodes. By means of a micro-buret, 0.300 cm^3 of water was added to the bomb which was then sealed.

The bomb was purged of nitrogen by filling with oxygen to 30 atm,[2] releasing the gas and refilling to 31.62 atm. The bomb was transferred to the calorimeter, the temperature of filling was determined and the bomb was heated electrically to 24.98 °C. The calorimeter jacket was evacuated, the adiabatic temperature controls placed in operation and the system left over-night.

On the following morning the pressure in the calorimeter jacket had been reduced to about 4.0×10^{-6} Pa. Calorimeter temperatures were observed at intervals during a 30-min initial rating period. An 18,000 μF condenser was charged to 24.5 V and discharged through the platinum wire which melted and ignited the sample. The quantity of electrical energy introduced for ignition was calculated from the drop in potential across the condenser and corrected for the portion dissipated in the connecting leads. It was not necessary to rotate the bomb during these experiments. When thermal equilibrium was established, calorimeter temperatures were observed at intervals during a 40-min final rating period. The observed temperature rise was obtained by extrapolation of the time-temperature curves, for the initial and final rating periods, to the actual time of ignition. A drift of approximately 0.001 °C/h was observed during the rating periods; this was due to the heating effect of the continuous 5 mA current through the platinum resistance thermometer.

The bomb was removed from the calorimeter assembly, the gaseous contens released and the bomb solution transferred to a glass beaker. The solution was boiled to expel carbon dioxide, cooled and titrated with standard alkali to determine the quantity of nitric acid produced from traces of nitrogen in the bomb atmosphere.

4. Results and Calculations

The results of the benzoic acid calibration experiments are given in table 1. All calculations including correction to standard conditions [3] were performed by computer with the tabulated values taken directly from the print-out and rounded for convenience. The headings, in the order in which they appear in the tables are described as follows:

EEE-Std, the effective energy equivalent of the standard, empty calorimeter;

Cv-cont(i), the heat capacity of the initial bomb contents, including the sample, crucible, water and oxygen;

Corr to tm, a correction to the heat capacity of the initial system for deviation of the actual mean temperature of the experiment from the standard mean temperature;

Corr-parts, a correction for alterations to the system during the series of experiments.

EEE-actual, the effective energy equivalent of the actual system at the actual mean temperature of the experiment;

Temp. rise, the observed increase in temperature of the system following ignition of the sample;

Q-total, the total quantity of energy evolved;

q-ign, the electrical energy added to the system to ignite the sample;

q-decomp HNO_3, the calculated quantity of energy required to decompose any nitric acid, formed in the combustion process, into nitrogen, oxygen and water;

q-WC, the Washburn Correction [3] applied to convert all reactants and products to their respective standard states at the actual final temperature;

q-corr to std t_f, a correction applied for deviation of the actual final temperature to the selected standard final temperature;

Q-std react, the energy evolved by the reaction with products and reactants in their respective standard states at the selected final temperature;

m_s, the mass of sample;

$\Delta Uc°$, the energy evolved by the standard reaction at the standard final temperature in $J \cdot g^{-1}$.

The following values were used in the calculations:

	Density, $g \cdot cm^{-3}$	Cp, $J \cdot g^{-1} \cdot K^{-1}$	$\left(\frac{\partial U}{\partial P}\right)_t$ $J \cdot g^{-1} \cdot atm^{-1}$
Benzoic acid.....	1.320	1.21	−0.0125
Cholesterol.....	1.067	1.46	−0.012

The density of cholesterol was taken from the Handbook of Chemistry and Physics [5]. The values taken for the heat capacity and the compressibility coefficients were estimated.

Other auxiliary data were taken from Wagman et al. [4]. The unit of energy is the joule; for conversion from the conventional thermo-chemical calorie, 1 calorie has been taken as equivalent to 4.1840 J.

For the calibration experiments, the value of EEE-Std was calculated by means of an iterative procedure from the mass of sample. Due to rounding of the individual items from the more exact values in the computer print-out, small differences may result by calculation from the tabulated data.

The results of the combustion experiments on

[2] 1 atm = 101325 Pa.

TABLE 1. *Results of the calibration experiments with benzoic acid*

Expt. No.	495	524	525	526	527	529
EEE-Std (26.5°C) ..... J/K...	2519.46	2519.63	2519.47	2519.70	2519.68	2519.46
Cv-cont(i) ..... J/K...	4.82	4.81	4.72	4.73	4.70	4.74
Corr to tm ..... J/K...	0.08	0.11	0.15	0.09	0.10	0.14
Corr-parts ..... J/K...	−0.16	0.00	0.00	0.00	0.00	0.00
EEE-actual ..... J/K...	2524.20	2524.55	2524.34	2524.52	2524.48	2524.34
Temp rise ..... K.....	3.133364	3.108335	3.159280	3.089474	3.100061	3.173467
Q-total ..... J.....	−7909.24	−7847.16	−7975.09	−7799.44	−7826.05	−8010.91
q-ign ..... J.....	1.22	1.06	1.18	0.79	1.11	1.16
q-decomp HNO_3 ..... J.....	0.70	0.21	0.30	0.47	0.17	0.84
q-WC ..... J.....	6.26	6.20	6.29	6.16	6.13	6.36
q-corr to 28°C ..... J.....	−0.04	−0.04	−0.06	−0.03	−0.04	−0.06
Q-std react ..... J.....	−7901.10	−7839.73	−7967.38	−7792.05	−7818.67	−8002.62
m_s ..... g.....	0.299167	0.296843	0.301676	0.295038	0.296046	0.303011
$\Delta Uc°$(28°C) ..... J/g...	−26410.36	−26410.36	−26410.36	−26410.36	−26410.36	−26410.36
Mean, EEE-std (26.5°C) ..... J/K...	2519.56					
sdm ..... J/K...	0.048					

TABLE 2. *Results of the cholesterol combustion experiments*

Expt. No.	517	518	519	520	521	522
EEE-Std (26.5°C) ..... J/K...	2519.56	2519.56	2519.56	2519.56	2519.56	2519.56
Cv-cont(i) ..... J/K...	4.70	4.71	4.70	4.72	4.72	4.70
Corr to tm ..... J/K...	0.06	0.07	−0.06	0.01	0.01	−0.01
Corr-parts ..... J/K...	0.00	0.00	0.00	0.00	0.00	0.00
EEE-actual ..... J/K...	2524.32	2524.34	2524.20	2524.29	2524.29	2524.25
Temp rise ..... K.....	3.052085	3.061326	2.923671	3.006016	3.000576	2.975157
Q-total ..... J.....	−7704.44	−7727.83	−7379.93	−7588.06	−7574.32	−7510.04
q-ign ..... J.....	0.99	0.89	0.89	1.04	1.04	0.89
q-decomp HNO_3 ..... J.....	0.13	0.42	0.42	0.15	0.19	0.20
q-WC ..... J.....	2.90	2.91	2.76	2.86	2.86	2.81
q-corr to 28°C ..... J.....	−0.03	−0.04	0.04	0.00	0.00	0.01
Q-std react ..... J.....	−7700.45	−7723.65	−7375.82	−7584.01	−7570.23	−7506.13
m_s ..... g.....	0.180520	0.181056	0.172901	0.177799	0.177491	0.175977
$\Delta Uc°$(28°C) ..... J/g...	−42657.04	−42658.90	−42659.21	−42654.96	−42651.35	−42654.04
Mean ..... J/g...	−42655.92					
sdm ..... J/g...	1.24					

cholesterol 911a are given in table 2. The results are summarized in table 3.

The uncertainties assigned to the values $\Delta Uc°$ and $\Delta Hc°$ were obtained by the combination of 2 sdm for the calibration experiments with 2 sdm for the combustion experiments, 0.01 percent for the uncertainty in the certified value for benzoic acid and 0.02 percent for the effects of possible impurities in the sample.

The uncertainty of 0.02 percent, assigned to the possible effect of impurities in the sample was obtained by assuming the impurity to consist of a similar organic substance for which the heat of combustion differed by 70 percent.

The uncertainty assigned to $\Delta Hf°$ was obtained by the combination of the uncertainty in $\Delta Hc°$ with 0.01 percent for the uncertainty in the heat of formation of carbon dioxide and 0.01 percent for the uncertainty in the heat of formation of water.

The results given in tables 2 and 3 correspond to the process:

$$C_{27}H_{46}O(c) + 38\ O_2(g) = 27\ CO_2(g) + 23\ H_2O(liq).$$

TABLE 3. *Summary of the results of this investigation*

$\Delta Uc°$ (28°C) = − 42655.9 ± 10.0 *J/g*
$\Delta Uc°$ (28°C) = − 16493.3 ± 3.9 kJ/mol
$\Delta Hc°$ (28°C) = − 16520.9 ± 3.9 kJ/mol
$\Delta Hc°$ (25°C) = − 16524.0 ± 3.9 kJ/mol
$\Delta Hf°$ (25°C) = − 674.8 ± 4.1 kJ/mol

5. Comparison With Other Reported Values

Berthelot and Andre [6] purified a commercial sample by digestion on a steam bath with calcium hydroxide and water. The cholesterol was taken up in ether, the ether was evaporated and the residue recrystallized from alcohol. The process was repeated until the elemental analysis showed the correct results. They performed two combustion experiments. Correction of their results to modern units and standard conditions yields − 16685 ± 166 kJ/mol (− 3987.9 ± 40 kcal/mol) for $\Delta Hc°$ (25 °C).

Bills, Cox, and Steel [7] removed ergosterol from a sample of cholesterol by succession bromination and debromination. The sample was recrystallied from alcohol and dehydrated for 15 h at 80 °C in high vacuum. They performed three combustion experiments with a precision of 0.3 percent. Correction of their data to current units yields − 16657 ± 50 kJ/mol (− 3981.1 ± 12.0 kcal/mol) for $\Delta Hc°$.

Paoli, Garrigues, and Patin [8] checked the purity of their sample by thin-layer chromatography and performed a series of micro-bomb combustion experiments with a precision of about 0.4 percent. They obtained − 16594 ± 66 kJ/mol (− 3966 ± 16 kcal/mol).

A tabulation of the existing data is given in table 4.

TABLE 4. *Comparison of results of prior investigations*

$\Delta Hc°$ (25°C), kJ/mol	Investigators
− 16685 ± 166	Berthelot and Andre [6]
− 16656 ± 50	Bills, Cox, and Steel [7]
− 16594 ± 66	Paoli, Garrigues, and Patin [8]
− 16524.0 ± 3.9	This investigation

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The Third Spectrum of Copper (Cu III)*

A. G. Shenstone**

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An analysis of Cu III based on observations from 500 to 6900 Å is presented. The low structures $3d^9$ and $3d^84s$ are complete, including the rarely, if ever before, found $3d^8(^1S)4s\,^2S$. The $3d^74s^2$ includes ^4F, ^2F, ^2G, and ^2H but the ^4P, ^2P, $a\,^2D$, $b\,^2D$ have eluded all attempts to find them. The ionization potential calculated from $4s$, $5s$, $6s\,^4F_{4\frac{1}{2}}$ is 296 980 cm_{-1} but by a comparison with Ni II which has a longer series an approximate value of 297 140 can be estimated. The $3d^84d$ group is complete, except for one level, as is $5d$ based on ^3F and ^1G, the other $5d$ groups being incomplete. $3d^8(^3F)4f$ is complete and 26 levels based on ^1D, ^3P, ^1G are known. $3d^8(^3F)5g$ is incomplete and a few levels based on ^1D and ^1G have been found. A discussion of the validity of the analysis of Cu IV by J. F. Schröder and Th. A. M. Van Kleef is given.

Key words: Atomic energy levels; atomic spectrum; copper; doubly ionized copper; electron configuration; ionization potential; wavelengths.

* An invited paper.

**Present address: Department of Physics, Princeton University, Princeton, N.J. 08540

1. Introduction

The anaylsis of the third spectrum of copper (Cu III) which is described in this paper, is the result of research by a number of spectroscopists. The work up to 1951 is summarized in the paper published in that year by A. G. Shenstone and L. Wilets [1][1] in which a correct description was given of the low structures and of a few higher ones. It was restricted, however, by the inadequacy of the condensed spark source which was the usual means, at that date, of exciting spectra of ionization above the second.

In 1956, Dr. W. C. Martin and I began to make a new description of the spectrum using the pulsed hollow cathode tube which had been recently introduced. The result was a new and much expanded line list which was adequate for the discovery of many new odd and even levels including $3d^7\,4s^2\,^4F$. Along with work on other spectra, I continued to work on that description of Cu III until 1965, when I came to the conclusion that I might gain a great deal by first making a very complete analysis of the isoelectronic spectrum Ni II. A second spectrum is more easily observed and analyzed because it can be produced with great purity and with fine lines by the hollow cathode tube discharge sometimes called a Schüler tube. An additional advantage was that the Bureau of Standards was then in a position to supply me with plates in the Schumann region taken with their 10.7 meter vacuum spectrograph. The Ni II analysis was published in 1970 [2] and I then returned to Cu III. In both Ni II and Cu III, I was greatly assisted by the kindness of Victor Kaufman of NBS who photographed the vacuum spectra on the 10.7 meter instrument using the hollow cathode, the pulsed hollow cathode, and the sliding spark. The dispersion of about .78 Å per mm. on the NBS plates much improved the accuracy of the data, in spite of the fact that the Doppler and Stark broadening of the lines reduced the resolution considerably. The six 18″ plates from NBS, which I measured several times with great care, consisted of the following:

(1) 2 plates 1400 to 2100 Å with a lithium fluoride filter to eliminate second order lines. The spectra consisted of two exposures using the ordinary hollow cathode, one exposure of the pulsed hollow cathode, and three of the sliding spark with increasing pulse current.

(2) 2 plates 820 to 1520 Å. Six spectra were taken,

[1] Figures in brackets indicate the literature references at the end of this paper.

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one being the ordinary hollow cathode and five being the pulsed hollow cathode. It was fortunate that those exposures are very good because that wavelength range includes a very large number of important transitions.

(3) 2 plates 0 to 950 Å with two hollow cathode exposures, one sliding spark and three pulsed hollow cathode exposures. The sliding spark exposure is obviously impure and the weakest pulsed hollow cathode does not extend below 850 Å. The other two are good but lack standards. Many of the strong lines are, however, calculable approximately, and almost all of them occur in second order on other plates where standards are available. Throughout the U–V spectrum, except as just mentioned, there are adequate standards of Cu II[3], C I [4], Si II [5], and Cl I [6] so that there are few regions where too long interpolations must be used. I made all measurements by eye, using a Societe Genevoise Comparator of 40 cm travel and accuracy about 2 μm. Intensity estimates were made on three exposures wherever available in order to obtain as much data as possible to distinguish Cu III and Cu IV lines. This is important because of the existence of the paper on Cu IV by Schröder and Van Kleef [7].

The spectra above 2000 Å were photographed on the Princeton 21 ft Paschen circle at about 1.3 Å per mm or, where necessary, in the first or second orders of our 21 ft Wadsworth spectrograph which uses a 15,000 line-per-inch grating.

Table 1 is the list of all lines attributed to Cu III. The total number of lines measured is about 3200 including both Cu III and Cu IV, and all were measured at least twice and many four or five times. Many small sections were remeasured wherever there was a question of close pairs or impurities.

2. Analysis

Table 2 is a synopsis of all the levels found. The chief structures expected in Cu III are due to the addition of an electron to $3d^8$(^{3}F, ^{3}P, ^{1}S, ^{1}D, ^{1}G). This includes the lowest term of all, $3d^9\,{}^2$D.

The much improved line list required the redetermination of the levels of the principal terms of $3d^8 4s$ and $3d^8 4p$. That then led to the determination of the levels of $3d^8 4d$ which had previously been the stumbling block which led to my analysis of Ni II [2]. The difficulty was revealed when 31 levels were found in the group, ten based on $3d^8\,{}^3$F$_4$, twelve instead of ten apparently on ^{3}F$_3$ and nine on ^{3}F$_2$. The extra two levels in the middle group have J-values of 5½ and 4½ and must be the two components of the term $3d^7 4s^2\,{}^2$H. They perturb the $3d^8 4d$ levels quite badly. As in Ni II, the $4d\,{}^2$D term is several thousand wave numbers above the other levels of the configuration.

The structure $3d^8 4s$ was known previously except for the predicted level $3d^8$ (^{1}S)$4s\,{}^2$S. The corresponding ^{2}P was identified when I noticed two strong lines at 542.902 Å and 553.012 Å which could hardly be anything but combinations with the two levels of $3d^9\,{}^2$D. This was confirmed by the discovery of the necessary satellite at 549.075 Å, completing the multiplet. It then became clear that the term involved must be $3d^8$ (^{1}S)$4p\,{}^2$P, and knowing the approximate position of ^{2}S, it was possible to find the combinations of ^{2}S and ^{2}P, thus fixing the true position of ^{2}S. I believe this is the first spectrum in which those levels have been found with certainty.

It is pertinent to make a few remarks about the naming of levels. It is obvious that in Ni II and Cu III we are dealing with spectra in which there is no pure Russell-Saunders coupling except in $3d^9\,{}^2$D. However, it has meaning and is useful to use R–S nomenclature throughout the analysis for the following reasons. The argument starts with the lowest term $3d^9\,{}^2$D which is pure R–S coupling and the $3d^8 4s\,{}^4$F and ^{2}F terms which are quite close to R–S coupling, the doublet being well removed from the quartet. Those levels combine with 18 levels of $3d^8$(^{3}F)$4p$ to give a pattern of intensities that reveals the characters of the 18 levels with very little doubt. There is evidently some mixing of ^{4}G$_{4½}$ and ^{4}F$_{4½}$, but there is enough evidence to distinguish them. Within the higher levels of $3d^8 4s$, there is some ambiguity between ^{2}D$_{2½}$ and ^{4}P$_{2½}$ but the intensities favor the choice made here. The $4s'''\,{}^2$G and its triad of odd terms are quite close to R–S coupling. The argument can be carried on step by step up to $3d^8 5g$

I have carried out that system of naming by intensities throughout the spectrum, and the nomenclature used is the same as that used in "Atomic Energy Levels" except that the levels are not grouped together in terms but are arranged numerically. The right-hand superscript has been omitted from the odd levels as unnecessary except in the case of a few numbered levels. Tables 3 and 4 are the lists of the even and odd levels found in this research.

Throughout this work I was very much helped by calculations made for me at NBS by Sugar and Martin [8]. They included $3d^8(4d\ \&\ 5s) + 3d^7 4s^2$; $3d^8(5d\ \&\ 6s)$; $3d^8 4p$; $3d^8 5p$; $3d^8 4f$; $3d^8 5g$. Their calculations made possible the discovery of a large number of levels, especially many of the levels of the prime, double-prime and triple-prime groups (Table 2) as well as the $4f$ and $5g$ configurations.

The $s^2\,{}^4$F was found some years ago from its combinations with the $4p$ levels and by extrapolation from Co I and Ni II. The ^{2}H was identified in the $4d$ group and ^{2}G and ^{2}F were named by using the calculated predictions. It is strange that the $s^2\,{}^4$P has evaded all my efforts to find it, though it must be fairly close to the predicted position.

In finding the levels of configurations built on ^{3}F, I have used a general regularity which impressed me in the analysis of Ni II. Taking as an example the group $5p\,{}^{4\,\&\,2}$DFG, the higher two J-values of each quartet are based on ^{3}F$_4$, the next three quartet levels and the three doublet levels of higher J are based on ^{3}F$_3$, and the remaining three quartet and three doublet levels are based on ^{3}F$_2$. The same scheme is applicable to the $4d$, $5d$, and $4f$ levels with some modifications because ^{4}S and ^{4}P do not have the requisite number of components. In $5g$ the scheme reaches an extreme which makes it possible to identify some, but not all of the levels. In fact, the number of combinations

TABLE 1. *Observed lines of Cu* III

λ (vac)	Intensity	Wavenumber	Transition
505.722	15	197737.1	
514.566	10	194338.5	
526.684	3	189867.2	$62065_{7/2} - 251932^\circ_{5/2}$
526.783	4	189831.5	$60805_{9/2} - 250636^\circ_{7/2}$
527.387	2	189614.1	$60805_{9/2} - 250419^\circ_{7/2}$
528.882	2	189078.1	$60805_{9/2} - 249883^\circ_{7/2}$
530.915	1	188354.1	$62065_{7/2} - 250419^\circ_{7/2}$
535.407	3	186773.8	$60805_{9/2} - 247578^\circ_{11/2}$
537.785	1	185947.9	$62065_{7/2} - 248013^\circ_{7/2}$?
538.105	5	185837.3	$62065_{7/2} - 247902^\circ_{9/2}$
538.487	1	185705.5	$60805_{9/2} - 246510^\circ_{9/2}$
539.382	1	185397.4	$60805_{9/2} - 246202^\circ_{7/2}$
540.513	0	185009.4	$63886_{3/2} - 248896^\circ_{3/2}$
540.930	25	184866.8	$60805_{9/2} - 245671^\circ_{7/2}$
541.185	0	184779.7	
541.345	0	184725.1	
542.312	1	184395.7	$63886_{3/2} - 248281^\circ_{5/2}$
542.378	20	184373.3	$62065_{7/2} - 249077^\circ_{9/2}$
542.493	40	184334.2	$60805_{9/2} - 245139^\circ_{11/2}$
542.902	75	184195.3	$0_{5/2} - 184197^\circ_{3/2}$
547.324	3	182707.1	
547.833	1	182537.4	$62065_{7/2} - 244602^\circ_{5/2}$
548.159	2	182428.8	$60805_{9/2} - 243234^\circ_{7/2}$
549.075	4	182124.5	$2071_{3/2} - 184197^\circ_{3/2}$
549.669	1	181927.7	
549.987	4	181822.5	
553.012	50	180827.9	$2071_{3/2} - 182900^\circ_{1/2}$
556.231	15	179781.4	
559.279	30	178801.6	$60805_{9/2} - 239606^\circ_{9/2}$
559.836	3	178623.7	
560.155	3	178522.0	
569.648	2	175547.0	
570.683	3	175228.6	
582.657	1	171627.6	$60805_{9/2} - 232435^\circ_{7/2}$
589.328	15	169684.8	
595.662	1	167880.4	
598.680	2	167034.1	$62065_{7/2} - 229098^\circ_{7/2}$
601.433	3	166269.6	$67016_{7/2} - 233285^\circ_{5/2}$
602.507	50	165973.2	$67016_{7/2} - 232989^\circ_{5/2}$
603.549	50	165686.6	$68963_{5/2} - 234650^\circ_{3/2}$
604.441	3	165442.1	$67016_{7/2} - 232458^\circ_{5/2}$
605.516	3	165148.4	
605.625	150	165118.7	$60805_{9/2} - 225923^\circ_{7/2}$
605.792	2	165073.2	$63886_{3/2} - 228960^\circ_{5/2}$
606.131	100	164980.8	
606.821	125	164793.2	$62065_{7/2} - 226857^\circ_{5/2}$
608.453	40	164351.2	$63143_{5/2} - 227494^\circ_{3/2}$
609.468	10	164077.5	$63886_{3/2} - 227964^\circ_{1/2}$
609.661	10	164025.6	$68963_{5/2} - 232989^\circ_{5/2}$
611.543	50	163520.8	
612.282	3	163323.4	
613.728	5	162938.6	
614.129	20	162832.2	
615.246	3	162536.6	
615.670	200	162424.7	$60805_{9/2} - 223229^\circ_{11/2}$
616.031	150	162329.5	$60805_{9/2} - 223134^\circ_{9/2}$
616.971	1	162082.2	$67016_{7/2} - 229098^\circ_{7/2}$
617.349	125	161982.9	$62065_{7/2} - 224048^\circ_{9/2}$
619.174	100	161505.5	$62065_{7/2} - 223570^\circ_{7/2}$
619.674	5	161375.2	
619.775	50	161348.9	$63886_{3/2} - 225235^\circ_{3/2}$
619.936	75	161307.0	$63143_{5/2} - 224450^\circ_{7/2}$
620.230	30	161230.5	
620.850	20	161069.5	$62065_{7/2} - 223134^\circ_{9/2}$
622.806	4	160563.6	$63886_{3/2} - 224450^\circ_{5/2}$
623.337	5	160426.9	$63143_{5/2} - 223570^\circ_{7/2}$
651.000	30	153609.8	$0_{5/2} - 153609^\circ_{7/2}$
653.871	1	152935.4	$62065_{7/2} - 215000^\circ_{7/2}$
655.638	2	152523.2	$62065_{7/2} - 214588^\circ_{9/2}$
657.074	10	152189.9	$60805_{9/2} - 212995^\circ_{9/2}$
658.342	3	151896.7	$63886_{3/2} - 215782^\circ_{3/2}$
658.609	0	151835.2	$89018_{9/2} - 240852^\circ_{9/2}$
659.022	0	151740.0	$89046_{7/2} - 240786^\circ_{7/2}$
659.110	15	151719.7	$60805_{9/2} - 212525^\circ_{11/2}$
659.533	3	151622.4	$63143_{5/2} - 214766^\circ_{5/2}$
659.587	5	151610.0	$60805_{9/2} - 212415^\circ_{9/2}$
659.810	2	151558.8	$63143_{5/2} - 214702^\circ_{5/2}$
659.935	4	151530.1	$63886_{3/2} - 215417^\circ_{5/2}$
661.053	0	151273.8	$63886_{3/2} - 215160^\circ_{1/2}$
661.169	8	151247.3	$62065_{7/2} - 213311^\circ_{7/2}$
661.312	5	151214.6	$63143_{5/2} - 214357^\circ_{3/2}$
661.445	5	151184.1	$63143_{5/2} - 214328^\circ_{7/2}$
661.681	0	151130.2	$77968_{5/2} - 229098^\circ_{7/2}$
662.180	20	151016.3	$60805_{9/2} - 211821^\circ_{7/2}$
662.424	10	150960.7	$62065_{7/2} - 213025^\circ_{5/2}$
662.556	0	150930.6	$62065_{7/2} - 212995^\circ_{9/2}$
663.213	1	150781.1	$80552_{5/2} - 231333^\circ_{3/2}$
664.651	5	150454.9	$77968_{5/2} - 228423^\circ_{5/2}$
665.114	2	150350.2	$62065_{7/2} - 212415^\circ_{9/2}$
665.868	1	150179.9	$78780_{3/2} - 228960^\circ_{5/2}$
666.116	3	150124.0	$89018_{9/2} - 239142^\circ_{11/2}$
667.819	4	149741.2	$89046_{7/2} - 238788^\circ_{9/2}$
672.668	50	148661.7	$0_{5/2} - 148663^\circ_{3/2}$
675.312	0	148079.7	$78780_{3/2} - 226857^\circ_{3/2}$?
675.753	3	147983.1	$67016_{7/2} - 215000^\circ_{7/2}$
675.884	10	147954.4	$77968_{5/2} - 225923^\circ_{7/2}$
676.566	75	147805.2	$0_{5/2} - 147806^\circ_{7/2}$
677.115	2	147685.4	$67016_{7/2} - 214702^\circ_{5/2}$
677.502	3	147601.0	$68963_{5/2} - 216565^\circ_{5/2}$
677.640	3	147571.0	$67016_{7/2} - 214588^\circ_{9/2}$
678.578	1	147367.0	$85447_{3/2} - 232814^\circ_{3/2}$
679.401	3	147188.5	$80305_{3/2} - 227494^\circ_{3/2}$
679.940	3	147071.8	$80423_{1/2} - 227494^\circ_{3/2}$
680.022	5	147054.1	$68963_{5/2} - 216017^\circ_{7/2}$
682.166	125	146591.9	$2071_{3/2} - 148663^\circ_{5/2}$
682.357	20	146550.8	$80305_{3/2} - 226857^\circ_{5/2}$?
685.024	1	145980.3	$67016_{7/2} - 212995^\circ_{9/2}$?
686.128	5	145745.4	$2071_{3/2} - 147817^\circ_{3/2}$
686.902	50	145581.2	$2071_{3/2} - 147653^\circ_{1/2}$
687.763	2	145398.9	$67016_{7/2} - 212415^\circ_{9/2}$
687.896	5	145370.8	$80552_{5/2} - 225923^\circ_{7/2}$
687.981	150	145352.8	$0_{5/2} - 145353^\circ_{3/2}$
690.249	40	144875.3	$0_{5/2} - 144876^\circ_{3/2}$
691.549	50	144602.9	$2071_{3/2} - 146675^\circ_{1/2}$
693.510	40	144194.0	$0_{5/2} - 144195^\circ_{5/2}$
697.926	20	143281.7	$2071_{3/2} - 145353^\circ_{3/2}$
700.186	40	142819.2	$0_{5/2} - 142820^\circ_{7/2}$
700.261	50	142803.9	$2071_{3/2} - 144876^\circ_{3/2}$
701.688	20	142513.5	$0_{5/2} - 142513^\circ_{3/2}$
702.118	25	142426.2	$[illegible]_{5/2} - 142427^\circ_{5/2}$
703.612	30	142123.8	$20[illegible]_{5/2} - 144195^\circ_{5/2}$
711.853	15	140478.4	$2[illegible]_{5/2} - 142550^\circ_{1/2}$
712.043	20	140441.0	$2[illegible]_{5/2} - 142513^\circ_{3/2}$
712.481	35	140354.6	$20[illegible]_{3/2} - 142427^\circ_{5/2}$
713.264	30	140200.5	$0_{5/2} - 140201^\circ_{3/2}$
715.532	150	139756.2	$0_{5/2} - 139757^\circ_{5/2}$
719.489	75	138987.5	$0_{5/2} - 138989^\circ_{3/2}$
719.520	75	138981.5	$0_{5/2} - 138982^\circ_{7/2}$
723.961	35	138129.0	$2071_{3/2} - 140201^\circ_{3/2}$
724.197	50	138084.0	$0_{5/2} - 138084^\circ_{5/2}$
726.296	30	137684.9	$2071_{3/2} - 139757^\circ_{5/2}$
728.920	10	137189.3	$2071_{3/2} - 139261^\circ_{1/2}$
730.375	125	136916.0	$2071_{3/2} - 138989^\circ_{3/2}$
732.029	100	136606.6	$0_{5/2} - 136607^\circ_{5/2}$
732.693	25	136482.8	$0_{5/2} - 136483^\circ_{3/2}$
735.229	100	136012.0	$2071_{3/2} - 138084^\circ_{5/2}$
743.298	100	134535.5	$2071_{3/2} - 136607^\circ_{5/2}$
743.986	35	134411.1	$2071_{3/2} - 136483^\circ_{3/2}$
777.119	150	128680.4	$0_{5/2} - 128679^\circ_{5/2}$
778.599	75	128435.8	$0_{5/2} - 128435^\circ_{3/2}$
788.071	250	126892.1	$0_{5/2} - 126892^\circ_{5/2}$
788.460	250	126829.5	$0_{5/2} - 126829^\circ_{7/2}$
789.837	100	126608.4	$2071_{3/2} - 128679^\circ_{3/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (vac)	Intensity	Wavenumber	Transition
791.365	250	126363.9	$2071\ {}_{3/2} - 128435°\ {}_{3/2}$
793.055	100	126094.7	$0\ {}_{3/2} - 126094°\ {}_{7/2}$
795.261	15	125744.9	$0\ {}_{3/2} - 125744°\ {}_{3/2}$
797.559	75	125382.6	$0\ {}_{3/2} - 125382°\ {}_{5/2}$
801.145	150	124821.3	$2071\ {}_{3/2} - 126892°\ {}_{5/2}$
802.840	100	124557.8	$0\ {}_{3/2} - 124557°\ {}_{7/2}$
808.579	40	123673.8	$2071\ {}_{3/2} - 125744°\ {}_{3/2}$
810.105	10	123440.8	$0\ {}_{3/2} - 123440°\ {}_{5/2}$
810.959	20	123310.8	$2071\ {}_{3/2} - 125382°\ {}_{5/2}$
816.297	12	122504.4	$0\ {}_{3/2} - 122504°\ {}_{7/2}$
820.591	0	121863.4	$0\ {}_{3/2} - 121864°\ {}_{3/2}$
829.345	100	120577.1	$0\ {}_{3/2} - 120577°\ {}_{5/2}$
829.429	10	120564.9	$2071\ {}_{3/2} - 122637°\ {}_{1/2}$
830.394	3	120424.8	$118864°\ {}_{7/2} - 239290\ {}_{9/2}$
833.654	5	119953.8	$118864°\ {}_{7/2} - 238818\ {}_{5/2}$
834.262	3	119866.4	$118864°\ {}_{7/2} - 238730\ {}_{7/2}$
834.782	15	119791.8	$2071\ {}_{3/2} - 121864°\ {}_{3/2}$
836.632	0	119526.9	$121864°\ {}_{3/2} - 241391\ {}_{3/2}$
836.922	1	119485.4	$120577°\ {}_{5/2} - 240062\ {}_{5/2}$
837.415	4	119415.1	$118864°\ {}_{7/2} - 238280\ {}_{9/2}$
840.269	1	119009.5	$146534°\ {}_{9/2} - 265544\ {}_{11/2}$
841.300	4	118863.7	$0\ {}_{3/2} - 118864°\ {}_{7/2}$
842.113	0	118748.9	$120577°\ {}_{5/2} - 239326\ {}_{3/2}$
842.828	3	118648.2	$123440°\ {}_{5/2} - 242088\ {}_{7/2}$
843.414	1	118565.7	$123440°\ {}_{5/2} - 242006\ {}_{5/2}$
843.843	12	118505.5	$2071\ {}_{3/2} - 120577°\ {}_{5/2}$
844.106	5	118468.5	$122504°\ {}_{7/2} - 240972\ {}_{9/2}$
844.160	1	118461.0	$121864°\ {}_{3/2} - 240325\ {}_{5/2}$
847.022	0	118060.7	$120577°\ {}_{5/2} - 238638\ {}_{7/2}$
847.801	4	117952.2	$121337°\ {}_{9/2} - 239290\ {}_{9/2}$
847.874	2	117942.1	$147647°\ {}_{11/2} - 265589\ {}_{13/2}$
848.740	2	117821.7	$122504°\ {}_{7/2} - 240325\ {}_{5/2}$
849.081	10	117774.4	$121337°\ {}_{9/2} - 239112\ {}_{11/2}$
850.760	2	117542.0	$121699°\ {}_{11/2} - 239240\ {}_{11/2}$
851.530	2	117435.7	
852.508	3	117301.0	$121337°\ {}_{9/2} - 238638\ {}_{7/2}$
852.548	20	117295.4	$121699°\ {}_{11/2} - 238994\ {}_{13/2}$
855.124	1	116942.1	$121337°\ {}_{9/2} - 238280\ {}_{9/2}$
856.360	3	116773.3	$124442°\ {}_{9/2} - 241215\ {}_{9/2}$
856.846	2	116707.1	$125382°\ {}_{5/2} - 242088\ {}_{7/2}$
857.767	20	116581.8	$121699°\ {}_{11/2} - 238280\ {}_{9/2}$
858.036	3	116545.2	$125744°\ {}_{3/2} - 242290\ {}_{5/2}$
858.241	15	116517.4	$124442°\ {}_{9/2} - 240960\ {}_{11/2}$
858.995	2	116415.1	$124557°\ {}_{7/2} - 240972\ {}_{9/2}$
860.554	4	116204.2	$126094°\ {}_{7/2} - 242297\ {}_{9/2}$
861.934	3	116018.2	$123550°\ {}_{9/2} - 239568\ {}_{9/2}$
863.105	5	115860.8	$124442°\ {}_{9/2} - 240303\ {}_{7/2}$
863.798	0	115767.8	$124557°\ {}_{7/2} - 240325\ {}_{5/2}$
864.008	1	115739.7	$123550°\ {}_{9/2} - 239290\ {}_{9/2}$
864.378	12	115690.1	$123550°\ {}_{9/2} - 239240\ {}_{11/2}$
864.768	1	115638.0	$138982°\ {}_{7/2} - 254620\ {}_{5/2}$
865.047	2	115600.7	$126094°\ {}_{7/2} - 241693\ {}_{5/2}$
868.646	1	115121.7	$126094°\ {}_{7/2} - 241215\ {}_{9/2}$
868.804	1	115100.8	$128679°\ {}_{5/2} - 243780\ {}_{5/2}$
868.898	2	115088.3	$123550°\ {}_{9/2} - 238638\ {}_{7/2}$
869.478	1	115011.5	$124557°\ {}_{7/2} - 239568\ {}_{9/2}$
870.451	1	114883.0	$124557°\ {}_{7/2} - 239440\ {}_{7/2}$
871.611	10	114730.1	$123550°\ {}_{9/2} - 238280\ {}_{9/2}$
874.230	1	114386.4	$126829°\ {}_{7/2} - 241215\ {}_{9/2}$
876.569	2	114081.1	$124557°\ {}_{7/2} - 238638\ {}_{7/2}$
877.729	3	113930.4	$128679°\ {}_{5/2} - 242610\ {}_{7/2}$
881.260	2	113473.9	$126829°\ {}_{7/2} - 240303\ {}_{7/2}$
884.845	3	113014.1	$128679°\ {}_{5/2} - 241693\ {}_{5/2}$
894.888	2	111745.8	$126892°\ {}_{5/2} - 238638\ {}_{7/2}$
941.369	1	106228.3	$77968\ {}_{5/2} - 184197°\ {}_{3/2}$
960.431	3	104119.9	$78780\ {}_{3/2} - 182900°\ {}_{1/2}$
964.789	5	103649.6	
1012.608	1	98754.9	
1012.665	2	98749.3	$85447\ {}_{3/2} - 184197°\ {}_{3/2}$
1033.419	5	96766.2	$86133\ {}_{1/2} - 182900°\ {}_{1/2}$
1042.934	10	95883.34	$118864°\ {}_{7/2} - 214747\ {}_{9/2}$
1048.880	40	95339.8	
1052.287	1	95031.1	$126829°\ {}_{7/2} - 221861\ {}_{7/2}$
1058.542	1	94469.6	$126094°\ {}_{7/2} - 220563\ {}_{9/2}$
1060.815	10	94267.1	$120577°\ {}_{5/2} - 214844\ {}_{7/2}$
1062.854	3	94086.3	$118864°\ {}_{7/2} - 212951\ {}_{5/2}$
1072.974	4	93198.9	$128679°\ {}_{5/2} - 221878\ {}_{5/2}$
1073.822	10	93125.3	$121864°\ {}_{3/2} - 214989\ {}_{5/2}$
1078.350	1	92734.3	$120577°\ {}_{5/2} - 213312\ {}_{3/2}$
1080.380	5	92560.0	$122637°\ {}_{1/2} - 215197\ {}_{3/2}$
1080.513	2	92548.6	$120577°\ {}_{5/2} - 213127\ {}_{3/2}$
1081.679	5	92448.9	$118864°\ {}_{7/2} - 211313\ {}_{9/2}$
1082.569	1	92372.9	$120577°\ {}_{5/2} - 212951\ {}_{5/2}$
1083.732	20	92273.7	
1089.246	1	91806.6	
1095.742	1	91262.4	$121864°\ {}_{3/2} - 213127\ {}_{3/2}$
1097.134	1	91146.6	
1098.775	1	91010.4	$118864°\ {}_{7/2} - 209875\ {}_{5/2}$
1107.574	1	90287.4	$124557°\ {}_{7/2} - 214844\ {}_{7/2}$
1132.874	3	88271.1	$126829°\ {}_{7/2} - 215100\ {}_{5/2}$
1142.133	3	87555.5	$128679°\ {}_{5/2} - 216235\ {}_{3/2}$
1147.815	1	87122.1	$124557°\ {}_{7/2} - 211679\ {}_{5/2}$
1149.405	1	87001.5	$60805\ {}_{9/2} - 147806°\ {}_{7/2}$
1154.825	5	86593.2	$67016\ {}_{7/2} - 153609°\ {}_{7/2}$
1157.149	20	86419.3	$138084°\ {}_{5/2} - 224503\ {}_{3/2}$
1158.697	1	86303.8	$126829°\ {}_{7/2} - 213133\ {}_{5/2}$
1161.993	2	86059.0	$126892°\ {}_{5/2} - 212951\ {}_{5/2}$
1165.037	2	85834.2	
1166.295	5	85741.6	$62065\ {}_{7/2} - 147806°\ {}_{7/2}$
1166.954	3	85693.2	
1169.022	1	85541.6	$125744°\ {}_{3/2} - 211286\ {}_{1/2}$
1169.312	0	85520.4	$63143\ {}_{5/2} - 148663°\ {}_{5/2}$
1169.376	5	85515.7	$138989°\ {}_{3/2} - 224503\ {}_{3/2}$
1174.588	20	85136.2	$128679°\ {}_{5/2} - 213815\ {}_{7/2}$
1177.311	4	84939.3	
1178.554	3	84849.7	$126829°\ {}_{7/2} - 211679\ {}_{5/2}$
1179.186	25	84804.3	$138982°\ {}_{7/2} - 223787\ {}_{5/2}$
1179.270	-3	84798.2	$138989°\ {}_{3/2} - 223787\ {}_{5/2}$
1179.807	4	84759.6	$126892°\ {}_{5/2} - 211652\ {}_{3/2}$
1180.559	2	84705.6	$128435°\ {}_{3/2} - 213141\ {}_{1/2}$
1181.391	1	84646.0	$68963\ {}_{5/2} - 153609°\ {}_{7/2}$
1182.887	15	84538.9	$169608\ {}_{3/2} - 254147°\ {}_{3/2}$
1183.606	3	84487.6	
1183.747	20	84477.5	$166159\ {}_{9/2} - 250636°\ {}_{7/2}$
1184.635	3	84414.2	$125744°\ {}_{3/2} - 210159\ {}_{5/2}$
1185.638	2	84342.8	
1186.223	2	84301.2	$140201°\ {}_{3/2} - 224503\ {}_{3/2}$?
1186.405	1	84288.2	$125744°\ {}_{3/2} - 210033\ {}_{3/2}$
1186.801	50	84260.1	$166159\ {}_{9/2} - 250419°\ {}_{7/2}$
1187.006	15	84245.6	$168856\ {}_{5/2} - 253102°\ {}_{3/2}$
1187.393	3	84218.1	$138982°\ {}_{7/2} - 223200\ {}_{9/2}$
1187.746	40	84193.1	$167739\ {}_{7/2} - 251932°\ {}_{5/2}$
1188.981	20	84105.6	$169608\ {}_{3/2} - 253713°\ {}_{1/2}$
1190.054	25	84029.8	$139757°\ {}_{5/2} - 223787\ {}_{5/2}$
1196.385	1	83585.1	$140201°\ {}_{3/2} - 223787\ {}_{3/2}$
1196.450	18	83580.6	$168856\ {}_{5/2} - 252437°\ {}_{5/2}$
1197.235	1	83525.8	
1197.535	10	83504.9	
1197.685	8	83494.4	$169608\ {}_{3/2} - 253102°\ {}_{3/2}$
1199.793	35	83347.7	$126892°\ {}_{5/2} - 210239\ {}_{7/2}$
1200.374	1	83307.4	
1200.449	1	83302.2	
1200.956	50	83267.0	$126892°\ {}_{5/2} - 210159\ {}_{5/2}$
1201.287	10	83244.1	$128435°\ {}_{3/2} - 211679\ {}_{5/2}$
1203.472	3	83092.9	
1203.725	25	83075.5	$168856\ {}_{5/2} - 251932°\ {}_{5/2}$
1203.782	3	83071.5	
1204.791	5	83001.9	
1205.067	20	82982.9	$126892°\ {}_{5/2} - 209875\ {}_{5/2}$
1206.014	10	82917.8	$166159\ {}_{9/2} - 249077°\ {}_{9/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (vac)	Intensity	Wavenumber	Transition
1206.303	20	82897.9	$167739_{7/2} - 250636°_{7/2}$
1206.996	10	82850.3	$128435°_{3/2} - 211286_{1/2}$
1207.300	5	82829.5	$169608_{3/2} - 252437°_{5/2}$
1212.073	2	82503.3	
1212.342	4	82485.0	$138084°_{5/2} - 220569_{7/2}$
1212.941	3	82444.2	$128679°_{5/2} - 211123_{3/2}$
1213.163	5	82429.2	$167739_{7/2} - 250168°_{7/2}$
1214.005	15	82372.0	
1214.173	1	82360.6	
1214.323	1	82350.4	$118864°_{7/2} - 201215_{5/2}$
1214.709	2	82324.2	$169608_{3/2} - 251932°_{5/2}$
1216.176	5	82224.9	
1216.395	12	82210.1	$63143_{5/2} - 145353°_{3/2}$
1216.532	2	82200.9	$166159_{9/2} - 248360°_{9/2}$
1217.361	5	82144.9	
1217.580	50	82130.1	$62065_{7/2} - 144195°_{5/2}$
1217.703	2	82121.8	$139757°_{5/2} - 221878_{5/2}$
1218.371	5	82076.8	$142427°_{5/2} - 224503_{3/2}$
1219.299	300	82014.3	$60805_{9/2} - 142820°_{7/2}$
1219.511	4	82000.1	
1219.725	30	81985.7	
1220.493	5	81934.1	
1221.678	5	81854.6	$166159_{9/2} - 248013°_{7/2}$
1221.742	10	81850.3	
1222.796	30	81779.8	$168856_{5/2} - 250636°_{7/2}$
1223.019	3	81764.9	$166159_{9/2} - 247924°_{9/2}$
1223.217	25	81751.6	
1223.347	75	81743.0	$166159_{9/2} - 247902°_{9/2}$
1223.507	10	81732.3	$63143_{5/2} - 144876°_{3/2}$
1223.639	40	81723.4	$128435°_{3/2} - 210159_{5/2}$
1223.959	25	81702.1	
1224.253	35	81682.5	$167739_{7/2} - 249421°_{5/2}$
1224.784	25	81647.0	$67016_{7/2} - 148663°_{5/2}$
1224.870	3	81641.3	
1225.269	1	81614.7	$167739_{7/2} - 249353°_{5/2}$
1225.526	20	81597.6	$128435°_{3/2} - 210033_{3/2}$
1225.778	20	81580.8	$138982°_{7/2} - 220563_{9/2}$
1226.091	10	81560.0	$128679°_{5/2} - 210239_{7/2}$
1227.830	15	81444.5	$169608_{3/2} - 251052°_{5/2}$
1228.210	150	81419.3	$166159_{9/2} - 247578°_{11/2}$
1229.108	3	81359.8	$142427°_{5/2} - 223787_{5/2}$
1229.439	50	81337.9	$167739_{7/2} - 249077°_{9/2}$
1229.771	3	81316.0	$166159_{9/2} - 247475°_{7/2}$
1229.847	25	81310.9	$168856_{5/2} - 250168°_{7/2}$
1230.412	1	81273.6	$142513°_{3/2} - 223787_{5/2}$
1232.469	1	81137.9	
1233.309	3	81082.7	
1233.788	30	81051.2	$63143_{5/2} - 144195°_{5/2}$
1234.932	1	80976.1	
1235.071	20	80967.0	$142820°_{7/2} - 223787_{5/2}$
1235.326	30	80950.3	
1235.643	15	80929.5	
1236.131	50	80897.6	
1236.260	1	80889.1	
1236.776	5	80855.4	
1237.204	50	80827.4	
1237.441	1	80811.9	$139757°_{5/2} - 220569_{7/2}$
1237.745	20	80792.1	
1237.780	50	80789.8	$67016_{7/2} - 147806°_{7/2}$
1237.905	10	80781.6	
1238.323 [a]	60	80754.4	$62065_{7/2} - 142820°_{7/2}$
1239.927	8	80649.9	
1240.126	6	80637.0	$120577°_{5/2} - 201215_{5/2}$
1240.216	15	80631.1	
1240.363	40	80621.6	$167739_{7/2} - 248360°_{9/2}$
1241.244	30	80564.3	$168856_{5/2} - 249421°_{5/2}$
1241.574	5	80542.9	$167739_{7/2} - 248281°_{5/2}$
1242.282	20	80497.0	$168856_{5/2} - 249353°_{5/2}$
1242.439	2	80486.8	
1243.016	1	80449.5	
1244.082	2	80380.6	$142820°_{7/2} - 223200_{9/2}$
1244.378	200	80361.4	$62065_{7/2} - 142427°_{5/2}$
1244.538	75	80351.1	$166159_{9/2} - 246510°_{9/2}$
1244.841	18	80331.5	
1245.204	15	80308.1	$144195°_{5/2} - 224503_{3/2}$
1245.643	5h	80279.8	$166159_{9/2} - 246439°_{9/2}$
1245.724	30	80274.6	$167739_{7/2} - 248013°_{7/2}$
1247.113	12	80185.2	$167739_{7/2} - 247924°_{9/2}$
1247.463	10	80162.7	$167739_{7/2} - 247902°_{9/2}$
1248.198	3	80115.5	
1249.108	15	80057.1	
1249.322	5h	80043.4	$166159_{9/2} - 246202°_{7/2}$
1249.376	20	80040.0	$168856_{5/2} - 248896°_{3/2}$
1250.429	15	79972.6	
1251.681	20	79892.6	$136483°_{3/2} - 216376_{5/2}$
1252.073	1	79867.5	$121864°_{3/2} - 201732_{3/2}$
1252.783	1	79822.3	$118864°_{7/2} - 198687_{9/2}$
1252.884	50	79815.8	
1253.261	20	79791.8	$137041°_{1/2} - 216833_{1/2}$
1253.631	30	79768.3	$136607°_{3/2} - 216376_{5/2}$
1253.984	25	79745.8	$169608_{3/2} - 249353°_{5/2}$
1254.136	25	79736.2	$167739_{7/2} - 247475°_{7/2}$
1254.711	100	79699.6	$68963_{5/2} - 148663°_{5/2}$
1254.777	20	79695.4	
1254.875	12	79689.2	
1255.082	15	79676.1	$63143_{5/2} - 142820°_{7/2}$
1255.314	35	79661.3	$136483°_{3/2} - 216145_{5/2}$
1255.848	35	79627.5	$136607°_{5/2} - 216235_{3/2}$
			$144876°_{3/2} - 224503_{3/2}$
1256.409	20	79591.9	$144195°_{5/2} - 223787_{5/2}$
1256.822	20	79565.8	
1257.273	50	79537.2	$136607°_{5/2} - 216145_{5/2}$
1257.672	75	79512.0	$166159_{9/2} - 245671°_{7/2}$
1259.052	50	79424.8	$168856_{5/2} - 248281°_{5/2}$
1259.503	12	79396.4	
1259.576	8	79391.8	
1259.934	150	79369.2	$63143_{5/2} - 142513°_{3/2}$
			$136607°_{5/2} - 215976_{7/2}$
1260.226	15	79350.8	$121864°_{3/2} - 201215_{5/2}$
1260.658	15	79323.7	$136483°_{3/2} - 215807_{3/2}$
1261.204	30	79289.3	$169608_{3/2} - 248896°_{3/2}$
1261.301	60	79283.2	$63143_{5/2} - 142427°_{5/2}$
1261.388	40	79277.7	$136483°_{3/2} - 215761_{1/2}$
1261.616	2	79263.4	
1261.928	3	79243.8	
1262.637	40	79199.3	$136607°_{5/2} - 215807_{3/2}$
1262.725	2	79193.8	$137041°_{1/2} - 216235_{3/2}$
1264.305	1	79094.8	$122637°_{1/2} - 201732_{3/2}$
1265.164	10	79041.1	$142820°_{7/2} - 221861_{7/2}$
1266.134	40	78980.6	$166159_{9/2} - 245139°_{11/2}$
1266.380	15	78965.2	
1267.252	10	78910.9	$144876°_{3/2} - 223787_{5/2}$
1267.855	15	78873.4	
1268.346	4	78842.8	$68963_{5/2} - 147806°_{7/2}$
1269.254	4	78786.4	
1269.587	60	78765.8	$137041°_{1/2} - 215807_{3/2}$
1270.181	8	78728.9	$118864°_{7/2} - 197593_{7/2}$
1270.327	20	78719.9	$137041°_{1/2} - 215761_{1/2}$
1270.484	2	78710.2	
1270.646	20	78700.1	$167739_{7/2} - 246439°_{9/2}$
1271.071	8	78673.8	$169608_{3/2} - 248281°_{5/2}$
1271.231	100	78663.9	$63886_{3/2} - 142550°_{1/2}$
1271.826	75	78627.1	$63886_{3/2} - 142513°_{3/2}$
1271.988	40	78617.1	$136483°_{3/2} - 215100_{5/2}$
1272.449	2	78588.6	$136607°_{5/2} - 215197_{3/2}$?
1272.710	8	78572.5	
1273.129	30	78546.6	
1273.231	15	78540.3	$63886_{3/2} - 142427°_{5/2}$
1273.703	35	78511.2	$118864°_{7/2} - 197375_{9/2}$
1273.790	10	78505.9	$136483°_{3/2} - 214989_{5/2}$
1273.904	2	78498.8	
1274.007	25	78492.5	$136607°_{5/2} - 215100_{5/2}$
1274.476	15	78463.6	$167739_{7/2} - 246202°_{7/2}$
1274.969	30	78433.3	$145353°_{3/2} - 223787_{5/2}$
1275.808	5	78381.7	$136607°_{5/2} - 214989_{3/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (vac)	Intensity	Wavenumber	Transition
1276.280	20	78352.7	$120577°_{3/2} - 198930_{7/2}$
1276.691	5	78327.5	
1277.081	30	78303.6	
1278.928	12	78190.5	$118864°_{7/2} - 197055_{7/2}$
1279.142	100	78177.4	$60805_{9/2} - 138982°_{7/2}$
1279.422	8	78160.3	
1281.064	18	78060.1	$138084°_{3/2} - 216145_{3/2}$
1281.617	3	78026.4	
1283.744	2	77897.1	
1283.829	2	77892.0	$138084°_{3/2} - 215976_{7/2}$
1284.259	18	77865.9	$118864°_{7/2} - 196730_{3/2}$
1284.877	35	77828.5	$146675°_{1/2} - 224503_{3/2}$
1285.677	15	77780.0	
1286.276	8	77743.8	$142820°_{7/2} - 220563_{9/2}$
1286.631	12	77722.4	$138084°_{3/2} - 215807_{3/2}$
1287.139	50	77691.7	$62065_{7/2} - 139757°_{3/2}$?
1287.256	12	77684.6	
1289.123	2	77572.1	$139261°_{1/2} - 216833_{1/2}$
1289.647	3	77540.6	
1290.598	35	77483.5	$120577°_{3/2} - 198061_{3/2}$
1291.504	2	77429.1	
1291.773	3	77413.0	
1291.860	10	77407.8	$120577°_{3/2} - 197985_{3/2}$
1292.011	12	77398.7	
1292.201	10	77387.3	$138989°_{3/2} - 216376_{5/2}$
1293.286	2	77322.4	$120577°_{3/2} - 197900_{3/2}$
1295.206	15	77207.8	$136607°_{3/2} - 213815_{7/2}$
1295.701	60	77178.3	$67016_{7/2} - 144195°_{3/2}$
1295.852	2	77169.3	
1295.944	30	77163.8	$118864°_{7/2} - 196028_{9/2}$
1296.075	20	77156.0	$138989°_{3/2} - 216145_{3/2}$
1297.438	30	77075.0	$166159_{9/2} - 243234°_{7/2}$
1297.580	5	77066.5	
1297.729	10	77057.7	$63143_{3/2} - 140201°_{3/2}$
1297.809	2	77052.9	
1298.433	40	77015.9	$120577°_{3/2} - 197593_{7/2}$
1298.653	3	77002.9	$144876°_{3/2} - 221878_{3/2}$
1299.216	20	76969.5	
1299.807	20	76934.5	$136483°_{3/2} - 213418_{1/2}$
1299.987	30	76923.8	$118864°_{7/2} - 195788_{7/2}$
1300.093	15	76917.6	$62065_{7/2} - 138982°_{7/2}$
1300.272	1	76907.0	$136607°_{3/2} - 213514_{3/2}$
1301.005	15	76863.7	$167739_{7/2} - 244602°_{3/2}$
1301.235	15	76850.1	$147653°_{1/2} - 224503_{3/2}$
1301.603	2	76828.3	$136483°_{3/2} - 213312_{1/2}$
1301.699	15	76822.7	$120577°_{3/2} - 197400_{3/2}$
1301.779	2	76818.0	$138989°_{3/2} - 215807_{3/2}$
1302.547	35	76772.7	$138989°_{3/2} - 215761_{1/2}$
1303.708	12	76704.3	$136607°_{3/2} - 213312_{3/2}$
1303.945	5	76690.3	$118864°_{7/2} - 195555_{3/2}$
1304.362	35	76665.8	$146534°_{9/2} - 223200_{9/2}$
1304.504	35	76657.5	$124557°_{7/2} - 201215_{5/2}$
1304.572	50	76653.5	$118864°_{7/2} - 195518_{9/2}$
1304.634	40	76649.8	$136483°_{3/2} - 213133_{5/2}$
1304.743	30	76643.4	$136483°_{3/2} - 213127_{3/2}$
1304.804	40	76639.9	$146534°_{9/2} - 223174_{7/2}$
1304.944	12	76631.6	$140201°_{3/2} - 216833_{1/2}$
1305.161	40	76618.9	$139757°_{5/2} - 216376_{5/2}$
1306.246	100	76555.3	$146534°_{9/2} - 223089_{9/2}$
1306.409	20	76545.7	$139261°_{1/2} - 215807_{3/2}$
1306.750	10	76525.7	$136607°_{3/2} - 213133_{5/2}$
1306.864	12	76519.1	$136607°_{3/2} - 213127_{3/2}$
1307.117	2	76504.2	
1307.186	5	76500.2	$139261°_{1/2} - 215761_{1/2}$
1307.573	100	76477.6	$120577°_{3/2} - 197055_{7/2}$
1307.610	50	76475.4	$118864°_{7/2} - 195340_{5/2}$
1309.069	15	76390.2	$68963_{5/2} - 145353°_{3/2}$
1309.113	25	76387.6	$139757°_{5/2} - 216145_{5/2}$
1309.882	50	76342.8	$136607°_{3/2} - 212951_{5/2}$
1311.124	60	76270.4	$137041°_{1/2} - 213312_{1/2}$
1311.847	75	76228.4	$120577°_{3/2} - 196806_{3/2}$
1312.001	10	76219.5	$139757°_{3/2} - 215976_{7/2}$
1312.391	200	76196.8	$118864°_{7/2} - 195061_{9/2}$
1312.630	5	76182.9	$122504°_{7/2} - 198687_{9/2}$
1312.867	30	76169.2	$121864°_{3/2} - 198033_{1/2}$
1312.950	30	76164.4	$120577°_{3/2} - 196742_{7/2}$
1313.295	75	76144.4	$136607°_{3/2} - 212752_{7/2}$
1313.697	50	76121.1	$121864°_{3/2} - 197985_{3/2}$
1314.062	50	76099.9	$137041°_{1/2} - 213141_{1/2}$
1314.933	25	76049.5	$139757°_{5/2} - 215807_{3/2}$
1315.208	5	76033.6	$140201°_{3/2} - 216235_{3/2}$
1315.455	40	76019.3	$62065_{7/2} - 138084°_{5/2}$
1316.131	100	75980.3	$147806°_{7/2} - 223787_{5/2}$
1317.312	20	75912.2	$68963_{5/2} - 144876°_{3/2}$
1318.483	20	75844.7	$63143_{5/2} - 138989°_{3/2}$
1318.574	60	75839.5	$148663°_{5/2} - 224503_{3/2}$
1318.689	30	75832.9	$125382°_{5/2} - 201215_{5/2}$
1319.204	25	75803.3	$67016_{7/2} - 142820°_{7/2}$
1319.870	15	75765.0	$138982°_{7/2} - 214747_{9/2}$
1320.208	4	75745.6	$168856_{5/2} - 244602°_{5/2}$
1320.469	40	75730.7	$138084°_{5/2} - 213815_{7/2}$
1320.513	50	75728.1	
1320.697	25	75717.6	$121337°_{9/2} - 197055_{7/2}$
1320.985	10	75701.1	$121337°_{9/2} - 197038_{11/2}$
1321.859	2	75651.0	
1322.655	30	75605.5	$140201°_{3/2} - 215807_{3/2}$
1323.456	20	75559.7	$140201°_{3/2} - 215761_{1/2}$
1323.501	20	75557.2	$122504°_{7/2} - 198061_{5/2}$
1323.575	40	75553.0	$147647°_{11/2} - 223200_{9/2}$
1324.025	50	75527.3	$147647°_{11/2} - 223175_{11/2}$
1324.108	25	75522.5	$120577°_{3/2} - 196100_{3/2}$
1324.502	3	75500.1	
1324.594	5	75494.8	$167739_{7/2} - 243234°_{7/2}$
1324.685	35	75489.6	$123440°_{5/2} - 198930_{7/2}$
1325.042	40	75469.3	$139261°_{1/2} - 214730_{1/2}$
1325.241	20	75458.0	$121337°_{9/2} - 196795_{9/2}$
1325.521	40	75442.0	$147647°_{11/2} - 223089_{9/2}$
1325.734	20	75429.9	$138084°_{5/2} - 213514_{3/2}$
1326.080	10	75410.2	$67016_{7/2} - 142427°_{5/2}$
1326.174	15	75404.9	$121337°_{9/2} - 196742_{7/2}$
1326.314	15	75396.9	$122504°_{7/2} - 197900_{3/2}$?
1326.362	75	75394.2	$147806°_{7/2} - 223200_{9/2}$
1326.453	8	75389.0	
1326.828	15	75367.7	$147806°_{7/2} - 223174_{7/2}$
1327.171	150	75348.2	$122637°_{1/2} - 197985_{3/2}$
1327.265	20	75342.9	$139757°_{5/2} - 215100_{5/2}$
1327.399	75	75335.3	$121864°_{3/2} - 197199_{1/2}$
1327.551	8	75326.7	$146534°_{9/2} - 221861_{7/2}$
1328.316	50	75283.3	$147806°_{7/2} - 223089_{9/2}$
1328.854	25	75252.8	$118864°_{7/2} - 194117_{7/2}$
1329.230	25	75231.5	$68963_{5/2} - 144195°_{5/2}$
1329.861	60	75195.8	$136483°_{3/2} - 211679_{3/2}$
1330.352	75	75168.1	$136483°_{3/2} - 211652_{3/2}$
1331.147	15	75123.2	$148663°_{5/2} - 223787_{5/2}$
1331.187	20	75120.9	$126094°_{7/2} - 201215_{5/2}$
1331.741	50	75089.7	$122504°_{7/2} - 197593_{7/2}$
1332.062	75	75071.6	$136607°_{3/2} - 211679_{3/2}$
1332.469	5	75048.6	$138084°_{5/2} - 213133_{5/2}$
1332.554	40	75043.9	$136607°_{3/2} - 211652_{3/2}$
1332.971	300	75020.4	$118864°_{7/2} - 193885_{5/2}$
1333.280	3	75003.0	$139261°_{1/2} - 214264_{3/2}$
1333.735	60	74977.4	$120577°_{3/2} - 195555_{3/2}$
1334.367	150	74941.9	$121864°_{3/2} - 196806_{3/2}$
1334.685	10	74924.0	
1334.832	10	74915.8	
1335.181	0?	74896.2	$122504°_{7/2} - 197400_{3/2}$
1336.184	60	74840.0	$126892°_{5/2} - 201732_{3/2}$
1336.310	30	74832.9	$138982°_{7/2} - 213815_{7/2}$
1336.859	40	74802.2	$136483°_{3/2} - 211286_{1/2}$
1337.116	3	74787.8	$140201°_{3/2} - 214989_{3/2}$
1337.508	50	74765.9	$120577°_{3/2} - 195343_{7/2}$
1337.567	150	74762.6	$120577°_{3/2} - 195340_{5/2}$
1338.849	75	74691.0	$121337°_{9/2} - 196028_{9/2}$
1339.271	30	74667.5	$138084°_{5/2} - 212752_{7/2}$
1339.345	20	74663.4	$136607°_{3/2} - 211271_{7/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (vac)	Intensity	Wavenumber	Transition
1339.484	200	74655.6	$118864^\circ_{7/2} - 193520_{7/2}$
1339.761	60	74640.2	$136483^\circ_{3/2} - 211123_{3/2}$
1340.880	15	74577.9	$121864^\circ_{3/2} - 196442_{3/2}$
1341.157	100	74562.5	$122637^\circ_{1/2} - 197199_{1/2}$
1341.470	100	74545.1	$123440^\circ_{5/2} - 197985_{3/2}$
1341.515	100	74542.6	$62065_{7/2} - 136607^\circ_{5/2}$
1341.766	5	74528.6	$140201^\circ_{3/2} - 214730_{1/2}$
1341.817	25	74525.8	$138989^\circ_{3/2} - 213514_{3/2}$
1341.997	40	74515.8	$136607^\circ_{5/2} - 211123_{3/2}$
1342.093	75	74510.5	$148663^\circ_{5/2} - 223174_{7/2}$
1342.177	150	74505.8	$118864^\circ_{7/2} - 193370_{9/2}$
1342.503	3	74487.7	$124442^\circ_{9/2} - 198930_{7/2}$
1343.007	100	74459.8	$123440^\circ_{5/2} - 197900_{5/2}$
1343.164	25	74451.1	$121337^\circ_{9/2} - 195788_{7/2}$
1343.721	100	74420.2	$121337^\circ_{9/2} - 195757_{11/2}$
1344.351	100	74385.3	$126829^\circ_{7/2} - 201215_{5/2}$
1345.483	80	74322.8	$126892^\circ_{5/2} - 201215_{5/2}$
1346.050	100	74291.4	$122504^\circ_{7/2} - 196795_{9/2}$
1346.903	60	74244.4	$124442^\circ_{9/2} - 198687_{9/2}$
1347.013	100	74238.3	$122504^\circ_{7/2} - 196742_{7/2}$
1347.059	75	74235.8	$121864^\circ_{3/2} - 196100_{3/2}$
1348.061	60	74180.6	$121337^\circ_{9/2} - 195518_{9/2}$
1348.268	30	74169.2	$122637^\circ_{1/2} - 196806_{3/2}$
1348.566	150	74152.8	$123440^\circ_{5/2} - 197593_{7/2}$
1348.714	40	74144.7	$138989^\circ_{3/2} - 213133_{5/2}$
1348.831	50	74138.3	$138989^\circ_{3/2} - 213127_{3/2}$
1349.420	300	74105.9	$120577^\circ_{5/2} - 194683_{3/2}$
1349.851	40	74082.2	$137041^\circ_{1/2} - 211123_{3/2}$
1350.032	20	74072.3	$147806^\circ_{7/2} - 221878_{5/2}$
1350.208	40	74062.7	$140201^\circ_{3/2} - 214264_{3/2}$
1350.280	80	74058.7	$121699^\circ_{11/2} - 195757_{11/2}$
1350.364	150	74054.1	$147806^\circ_{7/2} - 221861_{7/2}$
1350.557	3	74043.5	$123550^\circ_{9/2} - 197593_{7/2}$
1350.712	60	74035.0	$146534^\circ_{9/2} - 220569_{7/2}$
1350.816	15	74029.3	$146534^\circ_{9/2} - 220563_{9/2}$
1351.244	150	74005.9	$121337^\circ_{9/2} - 195343_{7/2}$
1352.085	2	73959.8	$123440^\circ_{5/2} - 197400_{5/2}$
1352.691	4	73926.7	
1353.545	50	73880.1	$139261^\circ_{1/2} - 213141_{1/2}$
1353.943	100	73858.4	$121864^\circ_{3/2} - 195722_{1/2}$
1354.658	30	73819.4	$121699^\circ_{11/2} - 195518_{9/2}$
1354.923	30	73804.9	$122637^\circ_{1/2} - 196442_{3/2}$
1355.442	100	73776.7	$146534^\circ_{9/2} - 220311_{11/2}$
1355.631	20	73766.4	
1356.406	150	73724.2	$121337^\circ_{9/2} - 195061_{9/2}$
1357.023	40	73690.7	$121864^\circ_{3/2} - 195555_{5/2}$
1357.308	50	73675.2	$136483^\circ_{3/2} - 210159_{5/2}$
1358.105	75	73632.0	$136607^\circ_{5/2} - 210239_{7/2}$
1358.428	75	73614.5	$123440^\circ_{5/2} - 197055_{7/2}$
1359.298	8	73567.4	$138084^\circ_{5/2} - 211652_{3/2}$
1359.355	5	73564.3	
1359.529	15	73554.9	$139757^\circ_{5/2} - 213312_{3/2}$
1359.615	75	73550.2	$142427^\circ_{3/2} - 215976_{7/2}$
1359.815	75	73539.4	$120577^\circ_{5/2} - 194117_{7/2}$
1360.087	25	73524.7	$122504^\circ_{7/2} - 196028_{9/2}$
1360.454	25	73504.9	$123550^\circ_{9/2} - 197055_{7/2}$
1360.761	25	73488.3	$123550^\circ_{9/2} - 197038_{11/2}$
1360.902	75	73480.7	$121337^\circ_{9/2} - 194818_{11/2}$
1360.987	60	73476.1	$121864^\circ_{3/2} - 195340_{5/2}$
1361.224	50	73463.3	$68963_{5/2} - 142427^\circ_{5/2}$
1361.517	30	73447.5	$166159_{9/2} - 239606^\circ_{9/2}$
1362.559	50	73391.3	$136483^\circ_{3/2} - 209875_{5/2}$
1362.840	50	73376.2	$139757^\circ_{5/2} - 213133_{5/2}$
1362.960	40	73369.7	$139757^\circ_{5/2} - 213127_{3/2}$
1363.083	150	73363.1	$121699^\circ_{11/2} - 195061_{9/2}$
1363.516	30	73339.8	$63143_{5/2} - 136483^\circ_{3/2}$
1364.014	15	73313.0	$140201^\circ_{3/2} - 213514_{3/2}$
1364.117	40	73307.5	$120577^\circ_{5/2} - 193885_{5/2}$
1364.227	100	73301.6	$123440^\circ_{5/2} - 196742_{7/2}$
1364.440	50	73290.1	$123440^\circ_{5/2} - 196730_{5/2}$
1364.548	5	73284.3	$122504^\circ_{7/2} - 195788_{7/2}$
1364.867	60	73267.2	$136607^\circ_{5/2} - 209875_{5/2}$
1365.275	20	73245.3	$123550^\circ_{9/2} - 196795_{9/2}$
1365.836	60	73215.2	$148663^\circ_{5/2} - 221878_{5/2}$
1366.241	40	73193.5	$139757^\circ_{5/2} - 212951_{5/2}$
1366.375	100	73186.3	$138084^\circ_{5/2} - 211271_{7/2}$
1367.627	150	73119.4	$121699^\circ_{11/2} - 194818_{11/2}$
1367.791	30	73110.6	$140201^\circ_{3/2} - 213312_{1/2}$
1368.257	50	73085.7	$122637^\circ_{1/2} - 195722_{1/2}$
1368.778	3?	73057.9	$80552_{5/2} - 153609^\circ_{7/2}$
1368.898	100	73051.5	$122504^\circ_{7/2} - 195555_{5/2}$
1369.130	40	73039.1	$138084^\circ_{5/2} - 211123_{3/2}$
1369.189	50	73035.9	$124557^\circ_{7/2} - 197593_{7/2}$
1369.593	100	73014.4	$122504^\circ_{7/2} - 195518_{9/2}$
1369.838	50	73001.3	$123440^\circ_{5/2} - 196442_{3/2}$
1369.958	60	72994.9	$139757^\circ_{5/2} - 212752_{7/2}$
1370.855	30	72947.2	$139261^\circ_{1/2} - 212208_{1/2}$
1370.936	40	72942.9	$120577^\circ_{5/2} - 193520_{7/2}$
1371.123	75	72932.9	$124442^\circ_{9/2} - 197375_{9/2}$
1371.267	25	72925.3	$140201^\circ_{3/2} - 213127_{3/2}$
1371.441	50	72916.0	$147647^\circ_{11/2} - 220563_{9/2}$
1372.878	75	72839.7	$122504^\circ_{7/2} - 195343_{7/2}$
1372.947	100	72836.0	$126094^\circ_{7/2} - 198930_{7/2}$
1373.282	75	72818.3	$124557^\circ_{7/2} - 197375_{9/2}$
1374.014	75	72779.5	$128435^\circ_{3/2} - 201215_{5/2}$
			$121337^\circ_{9/2} - 194117_{7/2}$
1374.275	100	72765.6	$147647^\circ_{11/2} - 220413_{13/2}$
1374.436	25	72757.1	$147806^\circ_{7/2} - 220563_{9/2}$
1374.751	100	72740.4	$67016_{7/2} - 139757^\circ_{5/2}$
1375.108	3	72721.6	$63886_{3/2} - 136607^\circ_{5/2}$
1375.337	2	72709.5	
1375.598	150	72695.7	$121337^\circ_{9/2} - 194033_{11/2}$
1375.693	40	72690.6	$138989^\circ_{3/2} - 211679_{5/2}$
1375.824	30	72683.7	$142513^\circ_{3/2} - 215197_{3/2}$
1375.909	100	72679.2	$125382^\circ_{5/2} - 198061_{5/2}$
1376.208	30	72663.4	$147647^\circ_{11/2} - 220311_{11/2}$
1376.278	10	72659.7	$123440^\circ_{5/2} - 196100_{3/2}$
1376.530	50	72646.4	$142550^\circ_{1/2} - 215197_{3/2}$
1376.787	300r	72632.9	$121699^\circ_{11/2} - 194331_{13/2}$
1377.174	40	72612.5	$124442^\circ_{9/2} - 197055_{7/2}$
1377.489	200r	72595.9	$124442^\circ_{9/2} - 197038_{11/2}$
1377.548	75	72592.8	$126094^\circ_{7/2} - 198687_{9/2}$
1377.656	30	72587.1	$142513^\circ_{3/2} - 215100_{5/2}$
1378.124	60	72562.4	$142427^\circ_{5/2} - 214989_{5/2}$
1378.214	75	72557.7	$122504^\circ_{7/2} - 195061_{9/2}$
1378.644	75	72535.0	$128679^\circ_{3/2} - 201215_{5/2}$
1379.362	75	72497.3	$124557^\circ_{7/2} - 197055_{7/2}$
1379.726	60	72478.2	$123550^\circ_{9/2} - 196028_{9/2}$
1379.769	70	72475.9	$142513^\circ_{3/2} - 214989_{5/2}$
1380.883	100	72417.4	$142427^\circ_{5/2} - 214844_{7/2}$
1381.395	50	72390.6	$139261^\circ_{1/2} - 211652_{3/2}$
1381.437	30	72388.4	
1382.120	50	72352.6	$124442^\circ_{9/2} - 196795_{9/2}$
1382.211	20	72347.9	$123440^\circ_{5/2} - 195788_{7/2}$
1382.472	40	72334.2	$121699^\circ_{11/2} - 194033_{11/2}$
1382.542	100	72330.5	$138982^\circ_{7/2} - 211313_{9/2}$
1382.811	50	72316.5	$125744^\circ_{3/2} - 198061_{5/2}$
1383.136	10?	72299.5	$124442^\circ_{9/2} - 196742_{7/2}$
1383.184	30	72297.0	$138989^\circ_{3/2} - 211286_{1/2}$
1383.341	40	72288.8	$125744^\circ_{3/2} - 198033_{1/2}$
			$138982^\circ_{7/2} - 211271_{7/2}$
1384.264	75	72240.6	$125744^\circ_{3/2} - 197985_{3/2}$
1384.324	100	72237.4	$124557^\circ_{7/2} - 196795_{9/2}$
1384.718	15	72216.9	$142513^\circ_{3/2} - 214730_{1/2}$
1384.822	150	72211.4	$125382^\circ_{5/2} - 197593_{7/2}$
1384.897	100	72207.5	$123550^\circ_{9/2} - 195757_{11/2}$
1385.366	60	72183.1	$121337^\circ_{9/2} - 193520_{7/2}$
1385.896	100	72155.5	$125744^\circ_{3/2} - 197900_{5/2}$
1386.292	35	72134.9	$138989^\circ_{3/2} - 211123_{3/2}$
1386.689	50	72114.2	$123440^\circ_{5/2} - 195555_{5/2}$
1386.948	50	72100.8	$126829^\circ_{7/2} - 198930_{7/2}$
1387.459	60	72074.2	$138084^\circ_{5/2} - 210159_{5/2}$
1387.992	25	72046.5	$122637^\circ_{1/2} - 194683_{3/2}$
1388.153	40	72038.2	$126892^\circ_{5/2} - 198930_{7/2}$

TABLE 1. *Observed lines of Cu* III – Continued

λ (vac)	Intensity	Wavenumber	Transition
1388.254	80	72032.9	$121337^{\circ}_{9/2} - 193370_{9/2}$
1388.412	50	72024.7	$139261^{\circ}_{1/2} - 211286_{1/2}$
			$142820^{\circ}_{7/2} - 214844_{7/2}$
1388.485	30	72020.9	$121864^{\circ}_{3/2} - 193885_{3/2}$
1389.508	150	71967.9	$123550^{\circ}_{9/2} - 195518_{9/2}$
1389.551	60	71965.7	$67016_{7/2} - 138982^{\circ}_{7/2}$
1389.708	15	71957.6	$144876^{\circ}_{3/2} - 216833_{1/2}$
1389.877	40	71948.8	$138084^{\circ}_{5/2} - 210033_{3/2}$?
1390.272	150	71928.4	$142820^{\circ}_{7/2} - 214747_{9/2}$
1390.389	30	71922.3	$139757^{\circ}_{5/2} - 211679_{5/2}$
1390.715	60	71905.5	$148663^{\circ}_{5/2} - 220569_{7/2}$
1390.827	1	71899.7	$123440^{\circ}_{5/2} - 195340_{5/2}$
1390.923	30	71894.7	$139757^{\circ}_{3/2} - 211652_{3/2}$
1391.443	2	71867.8	$167739_{7/2} - 239606^{\circ}_{9/2}$
1391.551	50	71862.3	$139261^{\circ}_{1/2} - 211123_{3/2}$
1391.647	100	71857.3	$126829^{\circ}_{7/2} - 198687_{9/2}$
1392.036	35	71837.2	$142427^{\circ}_{5/2} - 214264_{3/2}$
1392.631	50	71806.5	$126094^{\circ}_{7/2} - 197900_{5/2}$
1392.885	10	71793.4	$123550^{\circ}_{9/2} - 195343_{7/2}$
1392.944	15?	71790.4	$138084^{\circ}_{5/2} - 209875_{5/2}$
1393.117	80	71781.5	$144195^{\circ}_{5/2} - 215976_{7/2}$
1394.428	5	71714.0	$142550^{\circ}_{1/2} - 214264_{3/2}$
1395.250	150	71671.7	$121699^{\circ}_{11/2} - 193370_{9/2}$
1395.567	40	71655.5	$125744^{\circ}_{3/2} - 197375_{5/2}$
1396.394	60	71613.0	$122504^{\circ}_{7/2} - 194117_{7/2}$
1398.333	60	71513.7	$139757^{\circ}_{5/2} - 211271_{7/2}$
1398.379	80	71511.4	$123550^{\circ}_{9/2} - 195061_{9/2}$
1398.602	50	71499.9	$144876^{\circ}_{3/2} - 216376_{5/2}$
1399.000	60	71479.6	$145353^{\circ}_{3/2} - 216833_{1/2}$
1399.035	50	71477.8	$140201^{\circ}_{3/2} - 211679_{5/2}$
1399.171	150	71470.9	$124557^{\circ}_{7/2} - 196028_{9/2}$
1399.485	20	71454.9	$125744^{\circ}_{3/2} - 197199_{1/2}$
1399.574	40	71450.3	$140201^{\circ}_{3/2} - 211652_{3/2}$
1400.081	15	71424.4	$125382^{\circ}_{5/2} - 196806_{3/2}$
1400.783	20	71388.6	$142427^{\circ}_{5/2} - 213815_{7/2}$
1400.926	20	71381.4	$122504^{\circ}_{7/2} - 193885_{5/2}$
1401.333	25	71360.6	$125382^{\circ}_{5/2} - 196742_{7/2}$
1401.364	25	71359.0	$144876^{\circ}_{3/2} - 216235_{3/2}$
1401.566	60	71348.8	$125382^{\circ}_{5/2} - 196730_{5/2}$
1401.623	100	71345.9	$124442^{\circ}_{9/2} - 195788_{7/2}$
1402.226	100	71315.2	$124442^{\circ}_{9/2} - 195757_{11/2}$
1402.407	60	71306.0	$126094^{\circ}_{7/2} - 197400_{5/2}$
1402.885	50	71281.7	$126094^{\circ}_{7/2} - 197375_{9/2}$
1403.152	100	71268.1	$123550^{\circ}_{9/2} - 194818_{11/2}$
1403.371[a]	100	71257.0	$138982^{\circ}_{7/2} - 210239_{7/2}$
1403.750	30	71237.8	$68963_{5/2} - 140201^{\circ}_{3/2}$
1403.873	15	71231.5	$126829^{\circ}_{7/2} - 198061_{5/2}$
1404.963	30	71176.3	$138982^{\circ}_{7/2} - 210159_{5/2}$
1405.082	30	71170.2	$138989^{\circ}_{3/2} - 210159_{5/2}$
1405.099	30	71169.4	$126892^{\circ}_{5/2} - 198061_{5/2}$
1406.708	8	71088.0	$142427^{\circ}_{5/2} - 213514_{3/2}$
1406.946	8	71075.9	$124442^{\circ}_{9/2} - 195518_{9/2}$
1407.044	20	71071.0	$126829^{\circ}_{7/2} - 197900_{5/2}$
1407.105	50	71067.9	$67016_{7/2} - 138084^{\circ}_{5/2}$
1407.574	35	71044.2	$138989^{\circ}_{3/2} - 210033_{3/2}$
1408.006	100	71022.4	$145353^{\circ}_{3/2} - 216376_{5/2}$
1408.119	15	71016.7	$122504^{\circ}_{7/2} - 193520_{7/2}$
1408.291	50	71008.1	$126892^{\circ}_{5/2} - 197900_{5/2}$
1408.505	50	70997.3	$124557^{\circ}_{7/2} - 195555_{5/2}$
1409.224	50	70961.0	$126094^{\circ}_{7/2} - 197055_{7/2}$
1409.637	30	70940.2	
1409.820	15	70931.0	$144876^{\circ}_{3/2} - 215807_{3/2}$
1410.336	40	70905.1	$144195^{\circ}_{5/2} - 215100_{5/2}$
1410.336	40	70905.1	$142513^{\circ}_{3/2} - 213418_{1/2}$
1410.377	20?	70903.0	
1410.415	50	70901.1	$124442^{\circ}_{9/2} - 195343_{7/2}$
1410.597	75	70892.0	$138982^{\circ}_{7/2} - 209875_{5/2}$
1410.732	40	70885.2	$144876^{\circ}_{3/2} - 215761_{1/2}$
1411.085	30	70867.5	$142550^{\circ}_{1/2} - 213418_{1/2}$
1412.451	15	70798.9	$142513^{\circ}_{3/2} - 213312_{3/2}$
1412.555	40	70793.7	$68963_{5/2} - 139757^{\circ}_{5/2}$
1412.605	30	70791.2	$145353^{\circ}_{3/2} - 216145_{5/2}$
1412.709	75	70786.0	$124557^{\circ}_{7/2} - 195343_{7/2}$
1412.776	60	70782.6	$124557^{\circ}_{7/2} - 195340_{5/2}$
1412.997	75	70771.6	$139261^{\circ}_{1/2} - 210033_{3/2}$
1413.147	2	70764.0	$126829^{\circ}_{7/2} - 197593_{7/2}$
1413.190	1	70761.9	$142550^{\circ}_{1/2} - 213312_{1/2}$
1414.060	60	70718.4	$125382^{\circ}_{5/2} - 196100_{3/2}$
1414.291	8	70706.8	$142427^{\circ}_{5/2} - 213133_{5/2}$
1414.399	75	70701.4	$126094^{\circ}_{7/2} - 196795_{9/2}$
1414.481	65	70697.3	$125744^{\circ}_{3/2} - 196442_{3/2}$
1415.439	20	70649.5	$144195^{\circ}_{5/2} - 214844_{7/2}$
1415.464	30	70648.2	$126094^{\circ}_{7/2} - 196742_{7/2}$
1415.695	35	70636.7	$126094^{\circ}_{7/2} - 196730_{5/2}$
1415.855	10	70628.7	$142513^{\circ}_{3/2} - 213141_{1/2}$
1416.025	20	70620.2	$142513^{\circ}_{3/2} - 213133_{5/2}$
1416.153	40	70613.8	$142513^{\circ}_{3/2} - 213127_{3/2}$
1416.610	20	70591.1	$142550^{\circ}_{1/2} - 213141_{1/2}$
1416.906	15	70576.3	$142550^{\circ}_{1/2} - 213127_{3/2}$
1417.024	40	70570.4	$126829^{\circ}_{7/2} - 197400_{5/2}$
1417.096	50	70566.8	$123550^{\circ}_{9/2} - 194117_{7/2}$
1417.513	100	70546.1	$126829^{\circ}_{7/2} - 197375_{9/2}$
1417.960	30	70523.8	$142427^{\circ}_{5/2} - 212951_{5/2}$
1418.279	15	70508.0	$126892^{\circ}_{5/2} - 197400_{5/2}$
1418.358	50	70504.1	$124557^{\circ}_{7/2} - 195061_{9/2}$
1418.782	100	70483.0	$123550^{\circ}_{9/2} - 194033_{11/2}$
1419.378	5	70453.4	$145353^{\circ}_{3/2} - 215807_{3/2}$
1419.552	3	70444.8	$123440^{\circ}_{5/2} - 193885_{5/2}$
1419.691	10	70437.9	$142513^{\circ}_{3/2} - 212951_{5/2}$
1420.316	30	70406.9	$125382^{\circ}_{5/2} - 195788_{7/2}$
1420.945	30	70375.7	$124442^{\circ}_{9/2} - 194818_{11/2}$
1421.353	10	70355.5	$125744^{\circ}_{3/2} - 196100_{3/2}$
1421.701	3	70338.3	
1421.963	30	70325.3	$142427^{\circ}_{3/2} - 212752_{7/2}$
1422.049	5	70321.1	$144876^{\circ}_{3/2} - 215197_{3/2}$
1422.202	40	70313.5	$142820^{\circ}_{7/2} - 213133_{5/2}$
1422.964	30	70275.8	$139757^{\circ}_{5/2} - 210033_{3/2}$
1423.475	150	70250.6	$128679^{\circ}_{5/2} - 198930_{7/2}$
1423.984	75	70225.5	$126829^{\circ}_{7/2} - 197055_{7/2}$
1425.050	75	70173.0	$125382^{\circ}_{5/2} - 195555_{5/2}$
1425.253	50	70163.0	$126892^{\circ}_{5/2} - 197055_{7/2}$
1425.352	20	70158.1	$146675^{\circ}_{1/2} - 216833_{1/2}$
1425.904	50	70130.9	$142820^{\circ}_{7/2} - 212951_{5/2}$
1425.997	10	70126.4	
1426.171	30	70117.8	$139757^{\circ}_{3/2} - 209875_{5/2}$
1426.259	20	70113.5	$144876^{\circ}_{3/2} - 214989_{3/2}$
1427.161	60	70069.2	$144195^{\circ}_{5/2} - 214264_{3/2}$
1427.762	20	70039.7	$167739_{7/2} - 237778^{\circ}_{9/2}$
1428.064	150	70024.9	$68963_{3/2} - 138989^{\circ}_{3/2}$
1429.020	75	69978.0	$125744^{\circ}_{3/2} - 195722_{1/2}$
1429.179	100	69970.2	$123550^{\circ}_{9/2} - 193520_{7/2}$
1429.904	100	69934.8	$126094^{\circ}_{7/2} - 196028_{9/2}$
1429.960	80	69932.0	$142820^{\circ}_{7/2} - 212752_{7/2}$
1430.330	60?	69913.9	$126892^{\circ}_{5/2} - 196806_{3/2}$
1430.364	40?	69912.3	$126829^{\circ}_{7/2} - 196742_{7/2}$?
1430.587	5	69901.4	$126829^{\circ}_{7/2} - 196730_{5/2}$?
1430.948	100	69883.7	$78780_{3/2} - 148663^{\circ}_{3/2}$?
1431.550	20	69854.4	$144876^{\circ}_{3/2} - 214730_{1/2}$
1431.662	100	69848.9	$77968_{3/2} - 147817^{\circ}_{3/2}$
1431.875	75	69838.5	$77968_{3/2} - 147806^{\circ}_{7/2}$
			$126892^{\circ}_{5/2} - 196730_{5/2}$
1432.017	50	69831.6	$140201^{\circ}_{3/2} - 210033_{3/2}$
1432.249	100	69820.3	$123550^{\circ}_{9/2} - 193370_{9/2}$
1432.453	30	69810.3	$125744^{\circ}_{3/2} - 195555_{5/2}$
1432.759	8	69795.4	
1432.847	2	69791.1	
1433.760	30	69746.7	$145353^{\circ}_{3/2} - 215100_{5/2}$
1434.831	75	69694.6	$126094^{\circ}_{7/2} - 195788_{7/2}$
1435.265	30	69673.5	$140201^{\circ}_{3/2} - 209875_{5/2}$
1436.251	50	69625.7	$128435^{\circ}_{3/2} - 198061_{5/2}$
1436.363	60	69620.3	$144195^{\circ}_{5/2} - 213815_{7/2}$
1436.820	100	69598.1	$128435^{\circ}_{3/2} - 198033_{1/2}$
1436.973	100	69590.7	$124442^{\circ}_{9/2} - 194033_{11/2}$
1437.518	75	69564.3	$153609^{\circ}_{7/2} - 223174_{7/2}$
1437.623	100	69559.3	$124557^{\circ}_{7/2} - 194117_{7/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (vac)	Intensity	Wavenumber	Transition
1437.817	20	69549.9	$126892^{\circ}_{5/2} - 196442_{3/2}$
			$128435^{\circ}_{3/2} - 197985_{3/2}$
1439.264	80	69480.0	$153609^{\circ}_{7/2} - 223089_{9/2}$
1439.572	20	69465.1	$128435^{\circ}_{3/2} - 197900_{5/2}$
1440.417	75	69424.3	$126094^{\circ}_{7/2} - 195518_{9/2}$
1441.076	75	69392.6	$153808^{\circ}_{9/2} - 223200_{9/2}$
1441.163	40	69388.4	$144876^{\circ}_{3/2} - 214264_{3/2}$
1441.306	40	69381.5	$128679^{\circ}_{5/2} - 198061_{5/2}$
1441.411	30	69376.5	$145353^{\circ}_{3/2} - 214730_{1/2}$
1441.611	75	69366.8	$153808^{\circ}_{9/2} - 223175_{11/2}$
1442.414	100	69328.2	$124557^{\circ}_{7/2} - 193885_{5/2}$
1442.968	40	69301.6	$125382^{\circ}_{5/2} - 194683_{3/2}$
1443.384	30	69281.6	$153808^{\circ}_{9/2} - 223089_{9/2}$
1444.053	10	69249.5	$126094^{\circ}_{7/2} - 195343_{7/2}$
1444.565	15	69225.0	$142427^{\circ}_{5/2} - 211652_{3/2}$
1444.653	50	69220.8	$128679^{\circ}_{5/2} - 197900_{5/2}$
1444.919	60	69208.0	$126892^{\circ}_{5/2} - 196100_{3/2}$
1445.108	40	69199.0	$126829^{\circ}_{7/2} - 196028_{9/2}$
1445.217	35	69193.8	
1445.501	40	69180.2	$147653^{\circ}_{1/2} - 216833_{1/2}$
1446.508	5	69132.0	$146675^{\circ}_{1/2} - 215807_{3/2}$
1446.737	25	69121.1	$68963_{5/2} - 138084^{\circ}_{5/2}$
1446.824	25	69116.9	$144195^{\circ}_{5/2} - 213312_{3/2}$
1447.147	5	69101.5	$142550^{\circ}_{1/2} - 211652_{3/2}$
1447.636	20	69078.1	$124442^{\circ}_{9/2} - 193520_{7/2}$
1448.493	60	69037.3	$78780_{3/2} - 147817^{\circ}_{3/2}$
1448.933	10	69016.3	$147817^{\circ}_{3/2} - 216833_{1/2}$
1450.021	150	68964.5	$128435^{\circ}_{3/2} - 197400_{5/2}$
1450.141	75	68958.8	$126829^{\circ}_{7/2} - 195788_{7/2}$
1450.561	40	68938.8	$125744^{\circ}_{3/2} - 194683_{3/2}$
1450.788	15	68928.1	$124442^{\circ}_{9/2} - 193370_{9/2}$
1451.084	5	68914.0	$128679^{\circ}_{5/2} - 197593_{7/2}$
1451.155	20	68910.6	$145353^{\circ}_{3/2} - 214264_{3/2}$
1451.457	60	68896.3	$126892^{\circ}_{5/2} - 195788_{7/2}$
1451.943	10	68873.2	$78780_{3/2} - 147653^{\circ}_{1/2}$
1452.228	20	68859.7	$142820^{\circ}_{7/2} - 211679_{5/2}$
1452.544	10	68844.7	$142427^{\circ}_{5/2} - 211271_{7/2}$?
1453.213	15	68813.0	$124557^{\circ}_{7/2} - 193370_{9/2}$
1453.525	2	68798.3	$167739_{7/2} - 236537^{\circ}_{9/2}$
1454.246	15	68764.2	$128435^{\circ}_{3/2} - 197199_{1/2}$
1454.425	25	68755.7	$144195^{\circ}_{5/2} - 212951_{5/2}$
1454.861	25	68735.1	$125382^{\circ}_{5/2} - 194117_{7/2}$
1455.063	10	68725.5	$126829^{\circ}_{7/2} - 195555_{5/2}$
1455.174	50	68720.3	$128679^{\circ}_{5/2} - 197400_{5/2}$
1455.669	15	68696.9	$142427^{\circ}_{5/2} - 211123_{3/2}$
1455.842	40	68688.8	$126829^{\circ}_{7/2} - 195518_{9/2}$
1456.390	15	68662.9	$126892^{\circ}_{5/2} - 195555_{5/2}$
1456.905	45	68638.7	$144876^{\circ}_{3/2} - 213514_{3/2}$
1457.499	8	68610.7	$142513^{\circ}_{3/2} - 211123_{3/2}$
1458.370	30	68569.7	$147806^{\circ}_{7/2} - 216376_{5/2}$
1458.602	60	68558.8	$147817^{\circ}_{3/2} - 216376_{5/2}$
1459.556	50	68514.0	$126829^{\circ}_{7/2} - 195343_{7/2}$
1459.630	20	68510.5	$126829^{\circ}_{7/2} - 195340_{5/2}$
1459.778	10	68503.6	$125382^{\circ}_{5/2} - 193885_{5/2}$
1459.991	20	68493.6	$142820^{\circ}_{7/2} - 211313_{9/2}$
1460.893	75	68451.3	$142820^{\circ}_{7/2} - 211271_{7/2}$
			$126892^{\circ}_{5/2} - 195343_{7/2}$
1460.953	10	68448.5	$126892^{\circ}_{5/2} - 195340_{5/2}$
1461.604	15	68418.0	$147817^{\circ}_{3/2} - 216235_{3/2}$
1462.514	4	68375.4	$128679^{\circ}_{5/2} - 197055_{7/2}$
1462.885	60	68358.1	$80305_{3/2} - 148663^{\circ}_{5/2}$
1463.537	60	68327.6	$147817^{\circ}_{3/2} - 216145_{5/2}$
1464.234	50	68295.1	$128435^{\circ}_{3/2} - 196730_{5/2}$
1464.792	50	68269.1	$153609^{\circ}_{7/2} - 221878_{5/2}$
1465.040	3	68257.5	$144876^{\circ}_{3/2} - 213133_{5/2}$
1465.174	20	68251.3	$153609^{\circ}_{7/2} - 221861_{7/2}$
1466.919	15	68170.1	$147806^{\circ}_{7/2} - 215976_{7/2}$
1467.118	35	68160.8	$145353^{\circ}_{3/2} - 213514_{3/2}$
1467.188	15	68157.6	
1467.596	5	68138.6	$125382^{\circ}_{5/2} - 193520_{7/2}$
1467.857	30	68126.5	$128679^{\circ}_{5/2} - 196806_{3/2}$
1469.238	40	68062.5	$128679^{\circ}_{5/2} - 196742_{7/2}$
1469.406	40	68054.7	$146675^{\circ}_{1/2} - 214730_{1/2}$
1469.452	50	68052.6	$153808^{\circ}_{9/2} - 221861_{7/2}$?
1470.502	10	68004.0	
1470.807	60	67989.9	$147817^{\circ}_{3/2} - 215807_{3/2}$
1471.488	10	67958.4	$145353^{\circ}_{3/2} - 213312_{1/2}$
1471.797	45	67944.2	$147817^{\circ}_{3/2} - 215761_{1/2}$
1472.858	100	67895.2	$78780_{3/2} - 146675^{\circ}_{1/2}$
1474.796	8	67806.0	
1475.113	50	67791.4	$126892^{\circ}_{5/2} - 194683_{3/2}$
1475.189	10	67787.9	$145353^{\circ}_{3/2} - 213141_{1/2}$
1475.369	20	67779.7	$145353^{\circ}_{3/2} - 213133_{5/2}$
1475.509	25	67773.2	$145353^{\circ}_{3/2} - 213127_{3/2}$
1475.747	20	67762.3	$128679^{\circ}_{5/2} - 196442_{3/2}$
1476.405	10	67732.1	$142427^{\circ}_{5/2} - 210159_{5/2}$
1477.876	40	67664.7	$128435^{\circ}_{3/2} - 196100_{3/2}$
1478.325	40	67644.1	$68963_{5/2} - 136607^{\circ}_{5/2}$
1479.351	15	67597.2	$145353^{\circ}_{3/2} - 212951_{5/2}$
1479.524	15	67589.3	$146675^{\circ}_{1/2} - 214264_{3/2}$
1479.917	50	67571.4	$148663^{\circ}_{5/2} - 216235_{3/2}$
1481.050	50	67519.7	$68963_{5/2} - 136483^{\circ}_{3/2}$
1481.229	300r	67511.5	$80305_{3/2} - 147817^{\circ}_{3/2}$
1482.622	4	67448.1	$142427^{\circ}_{5/2} - 209875_{5/2}$
1483.084	4	67427.1	$126094^{\circ}_{7/2} - 193520_{7/2}$
1483.232	40	67420.3	$128679^{\circ}_{5/2} - 196100_{3/2}$
1483.816	150	67393.8	$80423_{1/2} - 147817^{\circ}_{3/2}$
1483.997	75	67385.6	$77968_{5/2} - 145353^{\circ}_{3/2}$
1484.831	40	67347.7	$80305_{3/2} - 147653^{\circ}_{1/2}$
1485.022	5	67339.1	$142820^{\circ}_{7/2} - 210159_{5/2}$
1485.170	20	67332.4	$144876^{\circ}_{3/2} - 212208_{1/2}$
1485.595	15	67313.1	$148663^{\circ}_{5/2} - 215976_{7/2}$
1486.021	50	67293.8	$147806^{\circ}_{7/2} - 215100_{5/2}$
1486.165	40	67287.3	$126829^{\circ}_{7/2} - 194117_{7/2}$
1486.257	35	67283.1	$147817^{\circ}_{3/2} - 215100_{5/2}$
1486.396	5	67276.8	$126094^{\circ}_{7/2} - 193370_{9/2}$
1486.655	150r	67265.1	$80552_{5/2} - 147817^{\circ}_{3/2}$
1486.892	100r	67254.4	$80552_{5/2} - 147806^{\circ}_{7/2}$
1487.282	5	67236.7	
1487.541	60	67225.0	$126892^{\circ}_{5/2} - 194117_{7/2}$
1488.471	30	67183.0	$147806^{\circ}_{7/2} - 214989_{5/2}$
1488.706	10	67172.4	$147817^{\circ}_{3/2} - 214989_{5/2}$
1489.347	20	67143.5	$148663^{\circ}_{5/2} - 215807_{3/2}$
1489.880	40	67119.5	$128435^{\circ}_{3/2} - 195555_{5/2}$
1490.344	15	67098.6	$122504^{\circ}_{7/2} - 189602_{7/2}$
1490.844	15	67076.1	$144195^{\circ}_{5/2} - 211271_{7/2}$
1491.300	40	67055.6	$142820^{\circ}_{7/2} - 209875_{5/2}$
1491.300	40	67055.6	$126829^{\circ}_{7/2} - 193885_{5/2}$
1493.437	60	66959.6	$153609^{\circ}_{7/2} - 220569_{7/2}$
1493.559	2	66954.2	$153609^{\circ}_{7/2} - 220563_{9/2}$
1493.843	40	66941.4	$147806^{\circ}_{7/2} - 214747_{9/2}$
1494.481	5	66912.9	$147817^{\circ}_{3/2} - 214730_{1/2}$
1494.590	60	66908.0	$77968_{5/2} - 144876^{\circ}_{3/2}$
1495.320	10	66875.3	$128679^{\circ}_{5/2} - 195555_{5/2}$
1495.778	20	66854.8	$145353^{\circ}_{3/2} - 212208_{1/2}$
1496.545	2	66820.6	
1496.927	4	66803.5	$144876^{\circ}_{3/2} - 211679_{5/2}$
1497.548	35	66775.8	$144876^{\circ}_{3/2} - 211652_{3/2}$
1497.900	40	66760.1	$121337^{\circ}_{9/2} - 188097_{9/2}$
1498.004	75	66755.5	$153808^{\circ}_{9/2} - 220563_{9/2}$
1498.604	50	66728.8	
1499.452	6	66691.0	$126829^{\circ}_{7/2} - 193520_{7/2}$
1500.060	40	66664.00	$128679^{\circ}_{5/2} - 195343_{7/2}$
1500.670	10	66636.90	$146675^{\circ}_{1/2} - 213312_{1/2}$
1501.171	100	66614.66	$62065_{7/2} - 128679^{\circ}_{5/2}$
1501.255	20	66610.93	$147653^{\circ}_{1/2} - 214264_{3/2}$
1502.093	100	66573.77	$78780_{3/2} - 145353^{\circ}_{3/2}$
1502.832	15	66541.04	$126829^{\circ}_{7/2} - 193370_{9/2}$
1503.691	10	66503.02	$153808^{\circ}_{9/2} - 220311_{11/2}$
1504.521	15	66466.34	$146675^{\circ}_{1/2} - 213141_{1/2}$
1504.853	15	66451.67	$146675^{\circ}_{1/2} - 213127_{3/2}$
1504.955	15	66447.17	$147817^{\circ}_{3/2} - 214264_{3/2}$
1505.197	5	66436.49	$148663^{\circ}_{5/2} - 215100_{5/2}$
1505.804	5	66409.70	$144876^{\circ}_{3/2} - 211286_{1/2}$
1506.716	50	66369.51	$80305_{3/2} - 146675^{\circ}_{1/2}$
1507.711	3	66325.71	$145353^{\circ}_{3/2} - 211679_{5/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (vac)	Intensity	Wavenumber	Transition
			$148663^{\circ}_{5/2} - 214989_{5/2}$
1508.336	30	66298.22	$145353^{\circ}_{3/2} - 211652_{3/2}$
1508.830	1	66276.52	$166159_{9/2} - 232435^{\circ}_{7/2}$
1509.392	40	66251.84	$80423_{1/2} - 146675^{\circ}_{1/2}$
1509.484	30	66247.80	$144876^{\circ}_{3/2} - 211123_{3/2}$
			$128435^{\circ}_{3/2} - 194683_{3/2}$
1509.955	125	66227.14	$77968_{5/2} - 144195^{\circ}_{5/2}$
1512.948	20	66096.12	$78780_{3/2} - 144876^{\circ}_{3/2}$
1514.593	100	66024.34	$60805_{9/2} - 126829^{\circ}_{7/2}$
1514.946	20	66008.95	$147806^{\circ}_{7/2} - 213815_{7/2}$
1515.063	40	66003.86	$128679^{\circ}_{5/2} - 194683_{3/2}$
1516.711	10	65932.14	$145353^{\circ}_{3/2} - 211286_{1/2}$
1523.023	3	65658.89	$147653^{\circ}_{1/2} - 213312_{1/2}$
1523.549	50	65636.22	
1523.921	5	65620.20	
1524.372	8	65600.78	$147817^{\circ}_{3/2} - 213418_{1/2}$
1524.539	4	65593.60	$122504^{\circ}_{7/2} - 188097_{9/2}$
1525.884	100	65535.78	$63143_{5/2} - 128679^{\circ}_{5/2}$
1525.945	20?	65533.16	$146675^{\circ}_{1/2} - 212208_{1/2}$
1526.839	25	65494.79	$147817^{\circ}_{3/2} - 213312_{1/2}$
1526.998	35	65487.97	$147653^{\circ}_{1/2} - 213141_{1/2}$
1528.695	10	65415.27	$78780_{3/2} - 144195^{\circ}_{5/2}$
1531.002	5	65316.70	$147817^{\circ}_{3/2} - 213133_{5/2}$?
1531.159	20	65310.00	$147817^{\circ}_{3/2} - 213127_{3/2}$
1531.588	30	65291.71	$63143_{5/2} - 128435^{\circ}_{3/2}$
1531.653	10	65288.94	$60805_{9/2} - 126094^{\circ}_{7/2}$
1535.310	2	65133.43	$147817^{\circ}_{3/2} - 212951_{5/2}$
1537.332	1	65047.76	$80305_{3/2} - 145353^{\circ}_{3/2}$
1541.976	100	64851.85	$77968_{5/2} - 142820^{\circ}_{7/2}$
1542.569	15	64826.92	$62065_{7/2} - 126892^{\circ}_{5/2}$
1543.172	20	64801.59	$80552_{5/2} - 145353^{\circ}_{3/2}$
1543.366	100	64793.44	$63886_{3/2} - 128679^{\circ}_{5/2}$
1543.455	200	64789.71	$89018_{9/2} - 153808^{\circ}_{9/2}$
1544.056	15	64764.49	$62065_{7/2} - 126829^{\circ}_{7/2}$
1544.132	50	64761.30	$89046_{7/2} - 153808^{\circ}_{9/2}$
1548.877	150	64562.91	$89046_{7/2} - 153609^{\circ}_{7/2}$
1549.215	50	64548.82	$63886_{3/2} - 128435^{\circ}_{3/2}$
1549.306	2	64545.03	$77968_{5/2} - 142513^{\circ}_{3/2}$
1554.617	20	64324.52	$80552_{5/2} - 144876^{\circ}_{3/2}$
1561.793	100	64028.97	$62065_{7/2} - 126094^{\circ}_{7/2}$
1565.202	125	63889.52	$80305_{3/2} - 144195^{\circ}_{5/2}$
1568.118	5	63770.71	$78780_{3/2} - 142550^{\circ}_{1/2}$
1568.567	50	63752.46	$60805_{9/2} - 124557^{\circ}_{7/2}$
1568.669	40	63748.31	$63143_{5/2} - 126892^{\circ}_{5/2}$
1569.044	40	63733.07	$78780_{3/2} - 142513^{\circ}_{3/2}$
1570.204	200	63685.99	$63143_{5/2} - 126829^{\circ}_{7/2}$
1570.975	1	63654.74	$124442^{\circ}_{9/2} - 188097_{9/2}$
1571.166	75	63647.00	$138084^{\circ}_{5/2} - 201732_{3/2}$
			$78780_{3/2} - 142427^{\circ}_{5/2}$
1571.265	20	63642.99	$80552_{5/2} - 144195^{\circ}_{5/2}$
1571.402	40	63637.44	$60805_{9/2} - 124442^{\circ}_{9/2}$
1579.361	75	63316.75	$62065_{7/2} - 125382^{\circ}_{5/2}$
1581.863	1	63216.60	$85447_{3/2} - 148663^{\circ}_{5/2}$
1588.554	75	62950.33	$63143_{5/2} - 126094^{\circ}_{7/2}$
1593.748	500r	62745.18	$60805_{9/2} - 123550^{\circ}_{9/2}$
1597.425	50	62600.75	$63143_{5/2} - 125744^{\circ}_{3/2}$
1600.185	400	62492.77	$62065_{7/2} - 124557^{\circ}_{7/2}$
1603.134	300	62377.82	$62065_{7/2} - 124442^{\circ}_{9/2}$
1605.960	200	62268.05	$80552_{5/2} - 142820^{\circ}_{7/2}$
1606.557	20	62244.91	$80305_{3/2} - 142550^{\circ}_{1/2}$
1606.723	300	62238.48	$63143_{5/2} - 125382^{\circ}_{5/2}$
1606.850	40	62233.56	$77968_{5/2} - 140201^{\circ}_{3/2}$
1607.524	100	62207.47	$80305_{3/2} - 142513^{\circ}_{3/2}$
1607.559	100	62206.11	$85447_{3/2} - 147653^{\circ}_{1/2}$
1609.597	100	62127.35	$80423_{1/2} - 142550^{\circ}_{1/2}$
1609.748	200	62121.52	$80305_{3/2} - 142427^{\circ}_{5/2}$
1610.570	150	62089.82	$80423_{1/2} - 142513^{\circ}_{3/2}$
1616.161	50	61875.02	$80552_{5/2} - 142427^{\circ}_{5/2}$
1616.605	200	61858.03	$63886_{3/2} - 125744^{\circ}_{3/2}$
1618.406	50	61789.19	$77968_{5/2} - 139757^{\circ}_{5/2}$
1620.774	15	61698.92	$60805_{9/2} - 122504^{\circ}_{7/2}$
1621.718	40	61663.00	$67016_{7/2} - 128679^{\circ}_{5/2}$
1625.496	30	61519.68	$86133_{1/2} - 147653^{\circ}_{1/2}$
1626.130	300	61495.70	$63886_{3/2} - 125382^{\circ}_{5/2}$
1626.405	300	61485.30	$62065_{7/2} - 123550^{\circ}_{9/2}$
1628.085	100	61421.85	$78780_{3/2} - 140201^{\circ}_{3/2}$
1628.290	300	61414.12	$63143_{5/2} - 124557^{\circ}_{7/2}$
1629.313	20	61375.56	$62065_{7/2} - 123440^{\circ}_{5/2}$
1630.356	75	61336.30	$122860_{1/2} - 184197^{\circ}_{3/2}$
1632.176	3	61267.90	$126829^{\circ}_{7/2} - 188097_{9/2}$
1633.239	8	61228.03	$85447_{3/2} - 146675^{\circ}_{1/2}$
1638.788	8	61020.71	$77968_{5/2} - 139757^{\circ}_{5/2}$
1638.945	300	61014.86	$77968_{5/2} - 138982^{\circ}_{7/2}$
1639.950	30	60977.47	$78780_{3/2} - 139757^{\circ}_{5/2}$
1641.419	1	60922.90	$128679^{\circ}_{5/2} - 189602_{7/2}$
1642.206	1000r	60893.70	$60805_{9/2} - 121699^{\circ}_{11/2}$
1651.754	50	60541.70	$86133_{1/2} - 146675^{\circ}_{1/2}$
1652.003	500	60532.58	$60805_{9/2} - 121337^{\circ}_{9/2}$
1653.400	75	60481.43	$78780_{3/2} - 139261^{\circ}_{1/2}$
1654.559	300	60439.06	$62065_{7/2} - 122504^{\circ}_{7/2}$
1658.457	300	60297.01	$63143_{5/2} - 123440^{\circ}_{5/2}$
1660.885	100	60208.86	$78780_{3/2} - 138989^{\circ}_{3/2}$
1663.431	3	60116.71	$77968_{5/2} - 138084^{\circ}_{5/2}$
1665.576	50	60039.29	$122860_{1/2} - 182900^{\circ}_{1/2}$
1669.267	40	59906.53	$85447_{3/2} - 145353^{\circ}_{3/2}$
1670.130	200	59875.58	$67016_{7/2} - 126892^{\circ}_{5/2}$
1671.873	250	59813.16	$67016_{7/2} - 126829^{\circ}_{7/2}$
1672.850	5	59778.22	$80423_{1/2} - 140201^{\circ}_{3/2}$
1674.588	200	59716.18	$68963_{5/2} - 128679^{\circ}_{5/2}$
1676.452	100	59649.78	$80552_{5/2} - 140201^{\circ}_{3/2}$
1677.365	150	59617.32	$89046_{7/2} - 148663^{\circ}_{5/2}$
1679.139	300	59554.33	$63886_{3/2} - 123440^{\circ}_{5/2}$
1681.462	150	59472.05	$68963_{5/2} - 128435^{\circ}_{3/2}$
1682.034	50	59451.83	$80305_{3/2} - 139757^{\circ}_{5/2}$
1682.680	100	59429.01	$85447_{3/2} - 144876^{\circ}_{3/2}$
1684.624	250	59360.43	$63143_{5/2} - 122504^{\circ}_{7/2}$
1686.194	200	59305.16	$78780_{3/2} - 138084^{\circ}_{5/2}$
1687.115	300	59272.78	$62065_{7/2} - 121337^{\circ}_{9/2}$
1688.609	50	59220.34	$86133_{1/2} - 145353^{\circ}_{3/2}$
1689.032	100	59205.51	$80552_{5/2} - 139757^{\circ}_{5/2}$
1692.686	200	59077.70	$67016_{7/2} - 126094^{\circ}_{7/2}$
1696.183	75	58955.90	$80305_{3/2} - 139261^{\circ}_{1/2}$
1699.574	3	58838.27	$80423_{1/2} - 139261^{\circ}_{1/2}$
1701.011	200	58788.57	$89018_{9/2} - 147806^{\circ}_{7/2}$
1702.104	400	58750.82	$63886_{3/2} - 122637^{\circ}_{1/2}$
1702.183	300	58748.09	$85447_{3/2} - 144195^{\circ}_{5/2}$
1702.334	35	58742.88	$86133_{1/2} - 144876^{\circ}_{3/2}$
1702.971	300	58720.91	$63143_{5/2} - 121864^{\circ}_{3/2}$
1704.061	30	58683.34	$80305_{3/2} - 138989^{\circ}_{3/2}$
1705.319	150	58640.05	$77968_{5/2} - 136607^{\circ}_{5/2}$
1705.620	200	58629.71	$89018_{9/2} - 147647^{\circ}_{11/2}$
1707.483	20	58565.74	$80423_{1/2} - 138989^{\circ}_{3/2}$
1708.935	100	58515.98	$77968_{5/2} - 136483^{\circ}_{3/2}$
1709.026	300	58512.86	$62065_{7/2} - 120577^{\circ}_{5/2}$
1711.245	75	58436.99	$80552_{5/2} - 138989^{\circ}_{3/2}$
1711.423	100	58430.91	$80552_{5/2} - 138982^{\circ}_{7/2}$
1713.336	30	58365.67	$67016_{7/2} - 125382^{\circ}_{5/2}$
1716.390	100	58261.82	$78780_{3/2} - 137041^{\circ}_{1/2}$
1722.369	500	58059.57	$60805_{9/2} - 118864^{\circ}_{7/2}$
1724.795	75	57977.90	$63886_{3/2} - 121864^{\circ}_{3/2}$
1726.265	30	57928.53	$68963_{5/2} - 126892^{\circ}_{5/2}$
1728.125	150	57866.18	$68963_{5/2} - 126829^{\circ}_{7/2}$
1730.724	5	57779.29	$80305_{3/2} - 138084^{\circ}_{5/2}$
1732.988	50	57703.80	$78780_{3/2} - 136483^{\circ}_{3/2}$
1737.888	100	57541.11	$67016_{7/2} - 124557^{\circ}_{7/2}$
1738.142	100	57532.70	$80552_{5/2} - 138084^{\circ}_{5/2}$
1738.646	75	57516.02	$89018_{9/2} - 146534^{\circ}_{9/2}$
1739.505	300	57487.62	$89046_{7/2} - 146534^{\circ}_{9/2}$
1741.131	75	57433.93	$63143_{5/2} - 120577^{\circ}_{5/2}$
1741.368	600	57426.12	$67016_{7/2} - 124442^{\circ}_{9/2}$
1750.386	400	57130.26	$68963_{5/2} - 126094^{\circ}_{7/2}$
1755.006	100	56979.86	$85447_{3/2} - 142427^{\circ}_{5/2}$
1760.580	75	56799.46	$62065_{7/2} - 118864^{\circ}_{7/2}$
1761.155	75	56780.92	$68963_{5/2} - 125744^{\circ}_{3/2}$
1762.555	100	56735.82	$80305_{3/2} - 137041^{\circ}_{1/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (vac)	Intensity	Wavenumber	Transition	λ (vac)	Intensity	Wavenumber	Transition
1763.948	1	56691.01	$63886\ ^{3/2} - 120577^{\circ}\ ^{5/2}$	1873.343	0	53380.51	$89046\ ^{7/2} - 142427^{\circ}\ ^{5/2}$
1766.221	50	56618.06	$80423\ ^{1/2} - 137041^{\circ}\ ^{1/2}$	1882.252	40	53127.85	$86133\ ^{1/2} - 139261^{\circ}\ ^{1/2}$
1768.861	200	56533.55	$67016\ ^{7/2} - 123550^{\circ}\ ^{9/2}$	1889.888	2	52913.19	$142427^{\circ}\ ^{5/2} - 195340\ ^{5/2}$
1772.299	2	56423.89	$67016\ ^{7/2} - 123440^{\circ}\ ^{5/2}$	1890.340	20	52900.54	$68963\ ^{5/2} - 121864^{\circ}\ ^{3/2}$
1772.483	50	56418.03	$68963\ ^{5/2} - 125382^{\circ}\ ^{5/2}$	1891.960	2	52855.24	$86133\ ^{1/2} - 138989^{\circ}\ ^{3/2}$
1773.697	20	56379.41	$86133\ ^{1/2} - 142513^{\circ}\ ^{3/2}$	1904.024	2	52520.35	$142820^{\circ}\ ^{7/2} - 195340\ ^{5/2}$
1776.129	75	56302.22	$80305\ ^{3/2} - 136607^{\circ}\ ^{5/2}$	1913.644	2	52256.32	$142427^{\circ}\ ^{5/2} - 194683\ ^{3/2}$
1780.059	30	56177.91	$80305\ ^{3/2} - 136483^{\circ}\ ^{3/2}$	1928.714	75	51848.02	$67016\ ^{7/2} - 118864^{\circ}\ ^{7/2}$
1783.792	75	56060.35	$80423\ ^{1/2} - 136483^{\circ}\ ^{3/2}$	1937.462	50	51613.91	$68963\ ^{5/2} - 120577^{\circ}\ ^{5/2}$
1783.941	30	56055.67	$80552\ ^{5/2} - 136607^{\circ}\ ^{5/2}$	1954.630	20	51160.58	$85447\ ^{3/2} - 136607^{\circ}\ ^{5/2}$
1787.902	10	55931.48	$80552\ ^{5/2} - 136483^{\circ}\ ^{3/2}$	1958.282	10	51065.17	$142820^{\circ}\ ^{7/2} - 193885\ ^{5/2}$
1798.757	30	55593.95	$68963\ ^{5/2} - 124557^{\circ}\ ^{7/2}$	1959.386	30	51036.40	$85447\ ^{3/2} - 136483^{\circ}\ ^{3/2}$
1826.339	100	54754.35	$85447\ ^{3/2} - 140201^{\circ}\ ^{3/2}$	1964.335	20	50907.81	$86133\ ^{1/2} - 137041^{\circ}\ ^{1/2}$
1835.643	2	54476.82	$68963\ ^{5/2} - 123440^{\circ}\ ^{5/2}$	1968.026	3	50812.34	
1840.913	200	54320.87	$67016\ ^{7/2} - 121337^{\circ}\ ^{9/2}$	1971.948	100	50711.28	$77968\ ^{5/2} - 128679^{\circ}\ ^{5/2}$
1849.525	15	54067.94	$86133\ ^{1/2} - 140201^{\circ}\ ^{3/2}$	1972.370	3	50700.43	$142820^{\circ}\ ^{7/2} - 193520\ ^{7/2}$
1858.251	5	53814.04	$85447\ ^{3/2} - 139261^{\circ}\ ^{1/2}$	1978.211	3	50550.72	$142820^{\circ}\ ^{7/2} - 193370\ ^{9/2}$
1858.678	20	53801.68	$89018\ ^{9/2} - 142820^{\circ}\ ^{7/2}$	1981.478	20	50467.38	$77968\ ^{5/2} - 128435^{\circ}\ ^{3/2}$
1867.023	2	53561.20	$67016\ ^{7/2} - 120577^{\circ}\ ^{5/2}$	1986.104	3	50349.83	$86133\ ^{1/2} - 136483^{\circ}\ ^{3/2}$
1867.747	100	53540.44	$68963\ ^{5/2} - 122504^{\circ}\ ^{7/2}$				

TABLE 1. *Observed lines of Cu* III – Continued

λ (air)	Intensity	Wavenumber	Transition
2000.781	50	49964.30	$89018_{9/2} - 138982°_{7/2}$
2001.917	2	49935.95	$89046_{7/2} - 138982°_{7/2}$
2003.367	1	49899.81	$78780_{3/2} - 128679°_{5/2}$
2013.225	200	49655.50	$78780_{3/2} - 128435°_{3/2}$
2038.577	50	49038.07	$89046_{7/2} - 138084°_{5/2}$
2043.326	100	48924.11	$77968_{5/2} - 126892°_{5/2}$
2077.046	75	48129.95	$80305_{3/2} - 128435°_{3/2}$
2077.141	20	48127.75	$80552_{5/2} - 128679°_{5/2}$
2077.813	5	48112.19	$78780_{3/2} - 126892°_{5/2}$
2083.452	2	47981.99	$147806°_{7/2} - 195788_{7/2}$
2087.742	15	47883.40	$80552_{5/2} - 128435°_{3/2}$
2092.408	15	47776.64	$77968_{5/2} - 125744°_{3/2}$
2108.420	30	47413.85	$77968_{5/2} - 125382°_{5/2}$
2112.314	15	47326.46	$211821°_{7/2} - 259147_{9/2}$?
2113.741	10	47294.51	$118864°_{7/2} - 166159_{9/2}$
2119.715	5	47161.24	$120577°_{5/2} - 167739_{7/2}$
2128.577	30	46964.91	$78780_{3/2} - 125744°_{3/2}$
2145.727	5	46589.58	$77968_{5/2} - 124557°_{7/2}$
2154.435	3	46401.29	$121337°_{9/2} - 167739_{7/2}$
2156.677	2	46353.06	$122504°_{7/2} - 168856_{5/2}$
2157.277	150	46340.17	$80552_{5/2} - 126892°_{5/2}$
2186.448	2	45721.98	
2217.768	3	45076.34	$80305_{3/2} - 125382°_{5/2}$
2244.680	1	44535.96	$77968_{5/2} - 122504°_{7/2}$
2248.491	6	44460.49	$121699°_{11/2} - 166159_{9/2}$
2271.728	25	44005.75	$80552_{5/2} - 124557°_{7/2}$
2277.395	40	43896.26	$77968_{5/2} - 121864°_{3/2}$
2279.102	10	43863.39	$125744°_{3/2} - 169608_{3/2}$
2279.416	15	43857.34	$78780_{3/2} - 122637°_{1/2}$
2299.473	100	43474.84	$125382°_{5/2} - 168856_{5/2}$
2312.353	12	43232.70	$85447_{3/2} - 128679°_{5/2}$
2315.103	20	43181.35	$124557°_{7/2} - 167739_{7/2}$
2318.815	0	43112.23	$125744°_{3/2} - 168856_{5/2}$
2320.306	100	43084.53	$78780_{3/2} - 121864°_{3/2}$
2323.268	2	43029.60	$193520_{7/2} - 236550°_{9/2}$
2323.972	2	43016.57	$193520_{7/2} - 236537°_{9/2}$
2325.370	5	42990.71	$194683_{3/2} - 237674°_{5/2}$
			$193520_{7/2} - 236511°_{7/2}$
2325.499	3	42988.33	$85447_{3/2} - 128435°_{3/2}$
2345.253	3	42626.27	$193885_{5/2} - 236511°_{7/2}$
2346.159	200	42609.81	$77968_{5/2} - 120577°_{5/2}$
2346.198	200	42609.10	$123550°_{9/2} - 166159_{9/2}$
2346.774	10	42598.64	
2347.470	3	42586.01	$193885_{5/2} - 236471°_{5/2}$
2353.652	10	42474.17	$195340_{5/2} - 237814°_{7/2}$
2354.848	10	42452.60	$211679_{5/2} - 254132°_{7/2}$
2357.160	1	42410.96	$195340_{5/2} - 237751°_{7/2}$
2358.775	3	42381.93	
2360.162	20	42357.02	$125382°_{5/2} - 167739_{7/2}$
2361.586	200	42331.48	$80305_{3/2} - 122637°_{1/2}$
2363.234	100	42301.96	$86133_{1/2} - 128435°_{3/2}$
2367.915	1	42218.35	
2368.174	500	42213.73	$80423_{1/2} - 122637°_{1/2}$
2377.788	5	42043.06	
2379.591	5	42011.21	$195722_{1/2} - 237734°_{3/2}$
2380.855	3	41988.91	
2382.033	10	41968.15	
2382.952	5	41951.96	$80552_{5/2} - 122504°_{7/2}$
2383.070	2	41949.88	$153808°_{9/2} - 195757_{11/2}$
2385.408	0	41908.77	$153609°_{7/2} - 195518_{9/2}$
2385.522	1	41906.77	$194683_{3/2} - 236590°_{5/2}$
2387.693	5	41868.67	$195722_{1/2} - 237591°_{1/2}$
2390.709	10	41815.85	$195722_{1/2} - 237538°_{3/2}$
2391.739	400	41797.85	$78780_{3/2} - 120577°_{3/2}$
2392.324	2	41787.63	$194683_{3/2} - 236471°_{5/2}$
2394.463	1	41750.30	$196028_{9/2} - 237778°_{9/2}$
2396.405	10	41716.47	$124442°_{9/2} - 166159_{9/2}$
2396.575	0	41713.51	$194818_{11/2} - 236531°_{11/2}$
2396.698	10	41711.37	$194683_{3/2} - 236395°_{3/2}$
2400.803	15	41640.05	$194683_{3/2} - 236323°_{1/2}$
2402.401	10	41612.36	$196028_{9/2} - 237641°_{11/2}$
2403.046	10	41601.19	$124557°_{7/2} - 166159_{9/2}$
2404.606	10	41574.20	$196100_{3/2} - 237674°_{5/2}$
2405.505	800	41558.67	$80305_{3/2} - 121864°_{3/2}$
2408.381	10	41509.04	$220311_{11/2} - 261820°_{11/2}$
2409.414	0	41491.25	$196100_{3/2} - 237591°_{1/2}$
2409.572	3	41488.53	$195061_{9/2} - 236550°_{9/2}$
2409.947	1	41482.07	
2410.645	3	41470.06	$195061_{9/2} - 236531°_{11/2}$
2412.107	400	41444.93	$85447_{3/2} - 126892°_{5/2}$
2412.338	700	41440.96	$80423_{1/2} - 121864°_{3/2}$
2413.188	2	41426.37	$220569_{7/2} - 261995°_{9/2}$
2417.243	5	41356.88	$195061_{9/2} - 236418°_{11/2}$
2419.858	30	41312.19	$80552_{5/2} - 121864°_{3/2}$
2420.033	15	41309.20	
2420.088	3	41308.26	
2421.836	150	41278.45	$212752_{7/2} - 254030°_{9/2}$
2422.266	0	41271.12	$195340_{5/2} - 236611°_{7/2}$
2423.070	2	41257.43	$213514_{5/2} - 254772°_{7/2}$
2423.502	1	41250.07	$195340_{5/2} - 236590°_{5/2}$
2426.058	0	41206.62	$195343_{7/2} - 236550°_{9/2}$
2428.151	75	41171.10	$195340_{5/2} - 236511°_{7/2}$
2430.345	200	41133.94	$193520_{7/2} - 234654°_{9/2}$
2430.528	100	41130.84	$195340_{5/2} - 236471°_{5/2}$
2431.728	3	41110.55	
2432.755	0	41093.19	$195518_{9/2} - 236611°_{7/2}$?
2433.499	3	41080.63	
2434.004	2	41072.11	$196742_{7/2} - 237814°_{7/2}$
2434.370	15	41065.93	
2435.048	15	41054.50	$195340_{5/2} - 236395°_{5/2}$
2435.824	300	41041.42	$193520_{7/2} - 234562°_{7/2}$
2436.107	3	41036.65	$196742_{7/2} - 237778°_{9/2}$
2436.388	10	41031.92	$195518_{9/2} - 236550°_{9/2}$
2436.843	5	41024.26	$196806_{3/2} - 237830°_{5/2}$
2437.168	10	41018.79	$195518_{9/2} - 236537°_{9/2}$
2437.482	4	41013.51	$195518_{9/2} - 236531°_{11/2}$
2437.774	3	41008.59	$196742_{7/2} - 237751°_{7/2}$
2438.130	2	41002.61	
2438.356	10	40998.81	$213127_{3/2} - 254125°_{5/2}$?
2439.269	20	40983.46	$196795_{9/2} - 237778°_{9/2}$
2440.072	200	40969.98	$193520_{7/2} - 234490°_{5/2}$
2440.884	5	40956.35	$195555_{5/2} - 236511°_{7/2}$
2441.933	15	40938.75	$148663°_{5/2} - 189602_{7/2}$
2442.582	125	40927.88	$196806_{3/2} - 237734°_{3/2}$
2443.701	20	40909.14	$126829°_{7/2} - 167739_{7/2}$
2444.122	10	40902.09	$196742_{7/2} - 237644°_{9/2}$
2444.233	250	40900.23	$195518_{9/2} - 236418°_{11/2}$
2444.439	2000	40896.79	$77968_{5/2} - 118864°_{7/2}$
2444.864	5	40889.68	$193885_{5/2} - 234775°_{5/2}$
2445.942	2	40871.66	
2446.164	15	40867.95	$196806_{3/2} - 237674°_{5/2}$?
2446.743	250	40858.28	$220311_{11/2} - 261169°_{13/2}$
2447.508	200	40845.51	$196795_{9/2} - 237641°_{11/2}$
2449.424	10	40813.56	$213312_{3/2} - 254125°_{5/2}$
2450.694	1	40792.41	$195757_{11/2} - 236550°_{9/2}$
2451.137	1	40785.04	$196806_{3/2} - 237591°_{1/2}$
2451.722	3	40775.31	$193885_{5/2} - 234660°_{3/2}$
2451.805	50	40773.93	$195757_{11/2} - 236531°_{11/2}$
2452.513	25	40762.16	$195722_{1/2} - 236484°_{3/2}$
2452.668	5	40759.58	$197055_{7/2} - 237814°_{7/2}$?
			$210239_{7/2} - 250999°_{9/2}$?
2452.980	300	40754.40	$220413_{13/2} - 261167°_{13/2}$
2453.758	8	40741.48	$194033_{11/2} - 234774°_{9/2}$
2454.312	5	40732.28	$196806_{3/2} - 237538°_{3/2}$
2454.819	5	40723.87	$197055_{7/2} - 237778°_{9/2}$
2456.499	3	40696.02	$197055_{7/2} - 237751°_{7/2}$
2457.661	30	40676.78	$193885_{5/2} - 234562°_{7/2}$
2458.691	400	40659.74	$195757_{11/2} - 236417°_{13/2}$
2459.396	250	40648.09	$195722_{1/2} - 236370°_{1/2}$
			$194033_{11/2} - 234681°_{11/2}$
2460.302	15	40633.12	$213815_{7/2} - 254448°_{9/2}$
2461.981	200	40605.41	$193885_{5/2} - 234490°_{5/2}$
2462.248	2	40601.01	$195722_{1/2} - 236323°_{1/2}$
2462.954	100	40589.37	$197055_{7/2} - 237644°_{9/2}$
2463.059	10	40587.64	

TABLE 1. *Observed lines of Cu* III—Continued

λ (air)	Intensity	Wavenumber	Transition
2463.657	5	40577.79	$210239_{7/2} - 250817°_{7/2}$
2463.860	150	40574.45	$210159_{5/2} - 250733°_{7/2}$
2465.848	100	40541.74	$193885_{5/2} - 234427°_{3/2}$
2466.297	3	40534.36	$197199_{1/2} - 237734°_{3/2}$
2467.873	25	40508.48	$196028_{9/2} - 236537°_{9/2}$
2468.191	50	40503.26	$196028_{9/2} - 236531°_{11/2}$
2468.411	500	40499.65	$194033_{11/2} - 234532°_{13/2}$
2468.725	300	40494.50	$210239_{7/2} - 250734°_{9/2}$
2468.777	10	40493.64	$210239_{7/2} - 250733°_{7/2}$
2468.987	50	40490.20	$196100_{3/2} - 236590°_{5/2}$
2469.433	1	40482.89	$196028_{9/2} - 236511°_{7/2}$
2471.454	1	40449.78	$147647°_{11/2} - 188097_{9/2}$
2474.503	3	40399.95	
2475.116	200	40389.94	$196028_{9/2} - 236418°_{11/2}$
2475.428	50	40384.85	$194331_{13/2} - 234716°_{11/2}$
			$196100_{3/2} - 236484°_{3/2}$
2477.593	1	40349.57	$194331_{13/2} - 234681°_{11/2}$
2478.236	400	40339.10	$194331_{13/2} - 234670°_{13/2}$
			$197199_{1/2} - 237538°_{3/2}$
2479.629	2	40316.44	$213815_{7/2} - 254132°_{7/2}$
2480.957	5	40294.86	$196100_{3/2} - 236395°_{3/2}$
2481.196	15	40290.98	$147806°_{7/2} - 188097_{9/2}$
2482.357	1000	40272.13	$80305_{3/2} - 120577°_{5/2}$
2482.782	10	40265.24	$197375_{9/2} - 237641°_{11/2}$
2485.267	3	40224.98	$153808°_{9/2} - 194033_{11/2}$?
2485.358	15	40223.51	$196100_{3/2} - 236323°_{1/2}$
2486.463	700	40205.64	$194331_{13/2} - 234537°_{15/2}$
2486.741	3	40201.14	$194331_{13/2} - 234532°_{13/2}$
2487.721	35	40185.31	$197593_{7/2} - 237778°_{9/2}$
2488.231	3	40177.07	$128679°_{5/2} - 168856_{5/2}$
2489.449	25	40157.41	
2490.972	3	40132.86	
2493.552	25	40091.34	$194683_{3/2} - 234775°_{5/2}$
2494.148	3	40081.76	$214844_{7/2} - 254926°_{7/2}$
2494.193	2	40081.04	$197593_{7/2} - 237674°_{5/2}$
2495.563	2	40059.04	
2496.078	350	40050.77	$197593_{7/2} - 237644°_{9/2}$
2496.962	2	40036.60	$214747_{9/2} - 254448°_{9/2}$
2497.638	400	40025.76	$80552_{5/2} - 120577°_{5/2}$
2497.867	10	40022.09	
2500.696	100	39976.82	$194683_{3/2} - 234660°_{3/2}$
2501.638	10	39961.76	
2501.975	1	39956.38	$194818_{11/2} - 234774°_{9/2}$
2503.029	75	39939.56	$214844_{7/2} - 254784°_{9/2}$
2503.180	5	39937.15	$214989_{5/2} - 254926°_{7/2}$
2503.327	2	39934.80	$85447_{3/2} - 125382°_{5/2}$
2503.625	75	39930.05	$197900_{5/2} - 237830°_{5/2}$
2504.629	150	39914.05	$197900_{5/2} - 237814°_{7/2}$
2505.609	200	39898.44	$194818_{11/2} - 234716°_{11/2}$
2505.762	10	39896.00	$221861_{7/2} - 261757°_{9/2}$
2506.527	10	39883.82	$221878_{5/2} - 261762°_{7/2}$
2506.720	125	39880.75	$196730_{5/2} - 236611°_{7/2}$
2507.452	150	39869.11	$196742_{7/2} - 236611°_{7/2}$
2507.832	5	39863.07	$194818_{11/2} - 234681°_{11/2}$
2508.052	125	39859.57	$196730_{5/2} - 236590°_{5/2}$
2508.488	500	39852.65	$194818_{11/2} - 234670°_{13/2}$
2508.612	75	39850.68	$197900_{5/2} - 237751°_{7/2}$
2508.775	5	39848.09	$196742_{7/2} - 236390°_{5/2}$
2508.848	50	39846.93	$194683_{3/2} - 234530°_{1/2}$
2508.965	15	39845.07	$197985_{3/2} - 237830°_{5/2}$
2509.515	15	39836.34	$194818_{11/2} - 234654°_{9/2}$
2509.687	3	39833.61	$197900_{5/2} - 237734°_{3/2}$
2510.802	2	39815.92	$196795_{9/2} - 236611°_{7/2}$
2511.297	200	39808.07	$196742_{7/2} - 236550°_{9/2}$
2512.137	15?	39794.76	$196742_{7/2} - 236537°_{9/2}$
2512.815	2	39784.03	$196806_{3/2} - 236590°_{5/2}$
2512.896	35	39782.74	$214989_{5/2} - 254772°_{7/2}$
2513.023	50	39780.73	$196730_{5/2} - 236511°_{7/2}$
2513.748	8	39769.26	$196742_{7/2} - 236511°_{7/2}$
2514.658	25	39754.87	$196795_{9/2} - 236550°_{9/2}$
2514.700	3	39754.21	$196730_{5/2} - 236484°_{3/2}$
2514.753	10	39753.37	$198061_{5/2} - 237814°_{7/2}$
2514.906	3	39750.95	$195061_{9/2} - 234812°_{7/2}$
2515.063	10	39748.47	$197985_{3/2} - 237734°_{3/2}$
2515.492	3	39741.69	$196795_{9/2} - 236537°_{9/2}$
2515.568	5	39740.49	$196730_{5/2} - 236471°_{5/2}$
2515.829	5	39736.37	$196795_{9/2} - 236531°_{11/2}$
2516.331	250	39728.44	$211271_{7/2} - 250999°_{9/2}$
2516.736	3	39722.05	
2516.866	250	39720.00	$214747_{9/2} - 254467°_{11/2}$
2517.214	3	39714.51	$194818_{11/2} - 234532°_{13/2}$
2517.321	100	39712.82	$195061_{9/2} - 234774°_{9/2}$
2517.687	15	39707.05	
2518.112	15	39700.34	$198033_{1/2} - 237734°_{3/2}$
2518.324	300	39697.00	$211313_{9/2} - 251010°_{11/2}$
2518.777	300	39689.86	$198061_{5/2} - 237751°_{7/2}$
2518.846	75	39688.78	$197985_{3/2} - 237674°_{5/2}$
2519.488	5	39678.66	$196806_{3/2} - 236484°_{3/2}$
2519.863	0	39672.76	$198061_{5/2} - 237734°_{3/2}$
2519.917	5	39671.91	$215100_{5/2} - 254772°_{7/2}$
2520.363	35	39664.89	$196806_{3/2} - 236471°_{5/2}$
2520.995	200	39654.95	$195061_{9/2} - 234716°_{11/2}$
2522.385	500	39633.09	$89046_{7/2} - 128679°_{5/2}$
2523.022	350	39623.09	$196795_{9/2} - 236418°_{11/2}$
2523.254	250	39619.45	$195061_{9/2} - 234681°_{11/2}$
2523.654	50	39613.17	$198061_{5/2} - 237674°_{5/2}$
2523.774	5	39611.28	$86133_{1/2} - 125744°_{3/2}$
2523.977	15	39608.10	$211123_{3/2} - 250731°_{5/2}$
2524.243	25	39603.92	$214844_{7/2} - 254448°_{9/2}$
2524.950	100d	39592.84	$195061_{9/2} - 234654°_{9/2}$
2525.213	25	39588.71	$196806_{3/2} - 236395°_{3/2}$
2526.755	10	39564.55	$196806_{3/2} - 236370°_{1/2}$
2527.189	35	39557.76	$198033_{1/2} - 237591°_{1/2}$
2527.495	10	39552.97	$197985_{3/2} - 237538°_{3/2}$
2527.913	3	39546.43	$211271_{7/2} - 250817°_{7/2}$
2528.552	3	39536.44	
2529.768	10	39517.44	$196806_{3/2} - 236323°_{1/2}$
2530.122	1	39511.91	$197038_{11/2} - 236550°_{9/2}$
2530.570	5	39504.91	$198033_{1/2} - 237538°_{3/2}$
2530.868	50	39500.26	$195061_{9/2} - 234562°_{7/2}$
2531.188	10	39495.27	$197055_{7/2} - 236550°_{9/2}$
2531.314	50	39493.30	$197038_{11/2} - 236531°_{11/2}$
2532.038	250	39482.01	$197055_{7/2} - 236537°_{9/2}$
2532.341	2	39477.29	$198061_{5/2} - 237538°_{3/2}$
2532.648	25	39472.50	$195340_{5/2} - 234812°_{7/2}$
2532.863	250	39469.15	$195343_{7/2} - 234812°_{7/2}$
2533.249	3	39463.14	$211271_{7/2} - 250734°_{9/2}$
2533.308	5	39462.22	$211271_{7/2} - 250733°_{7/2}$
2533.686	200	39456.33	$197055_{7/2} - 236511°_{7/2}$
2535.083	25	39434.59	$195340_{5/2} - 234775°_{5/2}$
2535.316	400	39430.97	$195343_{7/2} - 234774°_{9/2}$
2535.965	10	39420.88	$211313_{9/2} - 250734°_{9/2}$
2536.270	10	39416.14	$197055_{7/2} - 236471°_{5/2}$
2538.659	500	39379.05	$197038_{11/2} - 236417°_{13/2}$
2540.045	10	39357.56	$189602_{7/2} - 228960°_{5/2}$
2540.153	2	39355.89	
2540.446	5	39351.35	
2543.557	25	39303.22	$211652_{3/2} - 250955°_{5/2}$?
2543.738	3	39300.42	
2546.596	50	39256.32	$195518_{9/2} - 234774°_{9/2}$
2547.008	3	39249.97	
2547.938	3	39235.65	$197375_{9/2} - 236611°_{7/2}$
2548.841	10	39221.75	$195340_{5/2} - 234562°_{7/2}$
2549.071	2	39218.21	$195343_{7/2} - 234562°_{7/2}$
2549.185	5	39216.45	
2549.519	2	39211.32	$197400_{5/2} - 236611°_{7/2}$
2550.359	200	39198.40	$195518_{9/2} - 234716°_{11/2}$
2550.889	1	39190.26	$197400_{5/2} - 236590°_{5/2}$
2551.910	100	39174.58	$197375_{9/2} - 236550°_{9/2}$
2552.122	5	39171.33	$197199_{1/2} - 236370°_{1/2}$
2552.671	200	39162.90	$195518_{9/2} - 234681°_{11/2}$
2552.774	15	39161.32	$197375_{9/2} - 236537°_{9/2}$
2553.115	400	39156.09	$197375_{9/2} - 236531°_{11/2}$
2553.490	10	39150.34	$195340_{5/2} - 234490°_{5/2}$
2553.712	3	39146.94	$195343_{7/2} - 234490°_{5/2}$
2554.000	8	39142.52	$214989_{5/2} - 254132°_{7/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (air)	Intensity	Wavenumber	Transition
2554.295	75	39138.00	$211679_{5/2} - 250817°_{7/2}$
2554.419	125	39136.10	$195518_{9/2} - 234654°_{9/2}$
			$214989_{5/2} - 254125°_{5/2}$
2554.985	1	39127.44	$198687_{9/2} - 237814°_{7/2}$
2557.129	3	39094.63	
2557.315	25	39091.79	$198687_{9/2} - 237778°_{9/2}$
2557.656	15	39086.58	$195340_{5/2} - 234427°_{3/2}$
2560.460	10	39043.77	$195518_{9/2} - 234562°_{7/2}$
2561.251	15	39031.72	$215100_{5/2} - 254132°_{7/2}$
2561.737	5	39024.31	$195788_{7/2} - 234812°_{7/2}$
2562.163	5	39017.82	$197593_{7/2} - 236611°_{7/2}$
2564.176	10	38987.20	$215807_{3/2} - 254794°_{5/2}$
2564.247	8	38986.12	$195788_{7/2} - 234774°_{9/2}$
2565.188	3	38971.82	
2566.044	10	38958.82	$195757_{11/2} - 234716°_{11/2}$
2566.143	1	38957.31	$198687_{9/2} - 237644°_{9/2}$
2566.371	400	38953.85	$198687_{9/2} - 237641°_{11/2}$
2567.054	50	38943.49	$197593_{7/2} - 236537°_{9/2}$
2568.742	8	38917.90	$197593_{7/2} - 236511°_{7/2}$
2569.065	15	38913.01	$195757_{11/2} - 234670°_{13/2}$
2569.147	10	38911.77	$215761_{1/2} - 254673°_{3/2}$
2569.358	3	38908.57	$223089_{9/2} - 261998°_{11/2}$
2569.530	20	38905.97	$223089_{9/2} - 261995°_{9/2}$
2569.723	5	38903.04	
2569.908	5	38900.24	$198930_{7/2} - 237830°_{5/2}$
2570.139	1	38896.75	$195757_{11/2} - 234654°_{9/2}$
2570.266	3	38894.83	
2570.972	150	38884.15	$198930_{7/2} - 237814°_{7/2}$
2571.820	2	38871.32	
2572.747	10	38857.32	
2573.329	400	38848.53	$198930_{7/2} - 237778°_{9/2}$
2574.823	2	38825.99	
2574.998	30	38823.35	$223175_{11/2} - 261998°_{11/2}$
2575.119	35	38821.53	$223174_{7/2} - 261995°_{9/2}$
2575.166	1	38820.82	$198930_{7/2} - 237751°_{7/2}$
2576.023	15	38807.91	$195722_{1/2} - 234530°_{1/2}$
2576.454	3	38801.42	
2576.581	5	38799.50	
2576.724	30	38797.35	$223200_{9/2} - 261998°_{11/2}$
2577.594	1	38784.26	$196028_{9/2} - 234812°_{7/2}$
2577.765	35	38781.68	$216145_{5/2} - 254926°_{7/2}$
2578.212	150	38774.96	$195757_{11/2} - 234532°_{13/2}$
2580.135	125	38746.06	$196028_{9/2} - 234774°_{9/2}$
2581.173	125	38730.48	$223089_{9/2} - 261820°_{11/2}$
2582.264	5	38714.12	$198930_{7/2} - 237644°_{9/2}$
2582.478	2	38710.91	$197900_{5/2} - 236611°_{7/2}$
2583.882	1	38689.88	$197900_{5/2} - 236590°_{5/2}$
2584.001	15	38688.10	$196028_{9/2} - 234716°_{11/2}$
2584.888	5	38674.82	$196100_{3/2} - 234775°_{5/2}$
2585.012	3	38672.97	$223089_{9/2} - 261762°_{7/2}$
2585.393	1	38667.27	$223089_{9/2} - 261757°_{9/2}$
2586.369	75	38652.68	$196028_{9/2} - 234681°_{11/2}$
2586.589	5	38649.39	$216145_{5/2} - 254794°_{5/2}$
2587.420	150	38636.98	$223175_{11/2} - 261812°_{13/2}$
2588.068	10	38627.30	$216145_{5/2} - 254772°_{7/2}$
2588.159	10	38625.95	$196028_{9/2} - 234654°_{9/2}$
2588.594	10	38619.46	$223200_{9/2} - 261820°_{11/2}$
2589.159	10	38611.03	$197900_{5/2} - 236511°_{7/2}$
2589.573	10	38604.86	$197985_{3/2} - 236590°_{5/2}$
2590.677	15	38588.41	$223174_{7/2} - 261762°_{7/2}$
2591.102	3	38582.08	$223175_{11/2} - 261757°_{9/2}$?
2591.864	5	38570.73	$197900_{5/2} - 236471°_{5/2}$
2592.564	5	38560.32	$196100_{3/2} - 234660°_{3/2}$
2592.643	3	38559.15	$216235_{3/2} - 254794°_{5/2}$
2592.846	30	38556.13	$223200_{9/2} - 261757°_{9/2}$?
2593.244	2	38550.21	$198061_{5/2} - 236611°_{7/2}$
2594.370	1	38533.48	$196028_{9/2} - 234562°_{7/2}$
2594.648	0?	38529.35	$198061_{5/2} - 236590°_{5/2}$
2596.667	8	38499.40	$197985_{3/2} - 236484°_{3/2}$
2596.995	3	38494.53	$197900_{3/2} - 236395°_{3/2}$
2597.332	10	38489.54	
2598.522	50	38471.91	$215976_{7/2} - 254448°_{9/2}$
2599.240	3	38461.29	
2599.916	1	38451.29	$198033_{1/2} - 236484°_{3/2}$
2599.983	3	38450.30	$198061_{5/2} - 236511°_{7/2}$
2601.335	10	38430.31	$196100_{3/2} - 234530°_{1/2}$
2602.710	5	38410.01	$198061_{5/2} - 236471°_{5/2}$
2603.664	4	38395.94	$216376_{5/2} - 254772°_{7/2}$
2604.387	0	38385.28	$197985_{3/2} - 236370°_{1/2}$
2607.589	0	38338.15	$197985_{3/2} - 236323°_{1/2}$
2607.644	3	38337.34	$198033_{1/2} - 236370°_{1/2}$
2607.884	5	38333.81	$198061_{5/2} - 236395°_{3/2}$
2608.448	10	38325.53	
2609.320	500	38312.72	$80552_{5/2} - 118864°_{7/2}$
2611.473	10	38281.13	
2620.090	3	38155.24	$215976_{7/2} - 254132°_{7/2}$
2624.228	20	38095.08	
2625.116	15	38082.19	$196730_{5/2} - 234812°_{7/2}$
2625.924	0	38070.48	$196742_{7/2} - 234812°_{7/2}$
2627.063	1	38053.97	$215976_{7/2} - 254030°_{9/2}$
2627.738	10	38044.20	$196730_{5/2} - 234775°_{5/2}$
2628.491	10	38033.30	
2628.550	0	38032.45	$196742_{7/2} - 234774°_{9/2}$
2629.449	10	38019.44	
2632.238	5	37979.16	$196795_{9/2} - 234774°_{9/2}$
2635.667	3	37929.75	$196730_{5/2} - 234660°_{3/2}$
2636.258	1	37921.25	$196795_{9/2} - 234716°_{11/2}$
2636.891	0	37912.15	$196742_{7/2} - 234654°_{9/2}$?
2638.393	1	37893.57	$216235_{3/2} - 254125°_{5/2}$
2638.726	15	37885.79	$196795_{9/2} - 234681°_{11/2}$
2640.297	1	37863.25	$198687_{9/2} - 236550°_{9/2}$
2641.222	1	37849.99	$198687_{9/2} - 236537°_{9/2}$
2641.537	50	37845.47	$89046_{7/2} - 126892°_{5/2}$
2643.923	200	37811.32	$89018_{9/2} - 126829°_{7/2}$
2645.914	2	37782.87	$89046_{7/2} - 126829°_{7/2}$
2646.383	15	37776.17	$223787_{5/2} - 261563°_{7/2}$
2649.519	20	37731.47	$198687_{9/2} - 236418_{11/2}$
2652.095	4	37694.82	
2652.854	3	37684.03	$213133_{5/2} - 250817°_{7/2}$
2653.075	3	37680.89	$198930_{7/2} - 236611°_{7/2}$
2655.769	10	37642.67	$197038_{11/2} - 234681°_{11/2}$
2656.493	0	37632.42	$197038_{11/2} - 234670°_{13/2}$
2657.485	3	37618.37	
2658.314	20	37606.64	$198930_{7/2} - 236537°_{9/2}$
2658.822	3	37599.45	$197055_{7/2} - 234654°_{9/2}$
2660.128	2	37580.99	$198930_{7/2} - 236511°_{7/2}$
2665.384	3	37506.89	$197055_{7/2} - 234562°_{7/2}$
2670.481	30	37435.31	$197055_{7/2} - 234490°_{5/2}$?
2673.090	10	37398.77	$197375_{9/2} - 234774°_{9/2}$
2674.646	10	37377.02	
2677.231	2	37340.93	$197375_{9/2} - 234716°_{11/2}$
2679.773	50	37305.51	$197375_{9/2} - 234681°_{11/2}$
2679.963	3	37302.87	
2688.100	2	37189.95	$85447_{3/2} - 122637°_{1/2}$
2692.242	15	37132.74	
2696.378	200	37075.79	$89018_{9/2} - 126094°_{7/2}$
2698.441	50	37047.44	$89046_{7/2} - 126094°_{7/2}$
2707.844	5	36918.80	$213815_{7/2} - 250734°_{9/2}$
2707.904	1	36917.98	$213815_{7/2} - 250733°_{7/2}$
2708.317	8	36912.35	$197900_{5/2} - 234812°_{7/2}$
2711.102	8	36874.44	$197900_{5/2} - 234775°_{5/2}$
2719.540	2	36760.03	$197900_{5/2} - 234660°_{3/2}$
2725.573	5	36678.67	
2730.267	15	36615.61	$201215_{5/2} - 237830°_{5/2}$
2731.466	25	36599.54	$201215_{5/2} - 237814°_{7/2}$
2737.491	1	36518.99	$201215_{5/2} - 237734°_{3/2}$
2738.652	3	36503.51	$86133_{1/2} - 122637°_{1/2}$
2741.967	2	36459.38	$201215_{5/2} - 237674°_{5/2}$
2743.940	5	36433.17	
2751.330	20	36335.32	$89046_{7/2} - 125382°_{5/2}$
2769.378	10	36098.53	$201732_{3/2} - 237830°_{5/2}$
2776.817	10	36001.83	$201732_{3/2} - 237734°_{3/2}$
2777.510	0	35992.85	$153609°_{7/2} - 189602_{7/2}$
2781.424	5	35942.20	$201732_{3/2} - 237674°_{5/2}$
2787.865	2	35859.17	$201732_{3/2} - 237591°_{1/2}$
2791.966	0	35806.50	$201732_{3/2} - 237538°_{3/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (air)	Intensity	Wavenumber	Transition
2798.946	3	35717.21	$215100_{3/2} - 250817°_{7/2}$
2812.943	100	35539.49	$89018_{9/2} - 124557°_{7/2}$
2822.070	5	35424.55	$89018_{9/2} - 124442°_{9/2}$
2825.990	10	35375.42	$201215_{5/2} - 236590°_{5/2}$
2835.546	3	35256.21	$201215_{5/2} - 236471°_{5/2}$
2841.687	2	35180.02	$201215_{5/2} - 236395°_{3/2}$
2867.916	3	34858.29	$201732_{3/2} - 236590°_{5/2}$
2876.624	5	34752.77	$201732_{3/2} - 236484°_{3/2}$
2975.508	100	33597.90	$201215_{5/2} - 234812°_{7/2}$
2978.866	100	33560.03	$201215_{5/2} - 234775°_{5/2}$
2988.000	2	33457.44	$89046_{7/2} - 122504°_{7/2}$
2989.070	30	33445.47	$201215_{5/2} - 234660°_{3/2}$
3093.220	3	32319.39	$89018_{9/2} - 121337°_{9/2}$
3281.123	1	30468.59	$213311°_{7/2} - 243780_{3/2}$
3294.457	5	30345.28	$223787_{5/2} - 254132°_{7/2}$
3358.730	3	29764.60	
3394.340	2	29452.35	$214328°_{7/2} - 243780_{5/2}$
3438.088	10	29077.60	$214702°_{5/2} - 243780_{5/2}$
3445.623	3	29014.01	$214766°_{5/2} - 243780_{5/2}$
3473.651	3	28779.91	$215000°_{7/2} - 243780_{5/2}$
3533.762	2	28290.37	$201215_{5/2} - 229505°_{3/2}$
3542.052	2	28224.16	$213025°_{5/2} - 241249_{7/2}$
3545.430	10	28197.27	$238833°_{7/2} - 267031_{3/2}$
3548.870	75	28169.94	$216448°_{3/2} - 244618_{3/2}$
3549.926	10	28161.56	$239148°_{5/2} - 267310_{3/2}$
3555.834	5	28114.77	
3558.126	8	28096.66	
3563.695	30	28052.75	$216565°_{5/2} - 244618_{3/2}$
3564.251	20	28048.38	$213025°_{5/2} - 241074_{7/2}$
3568.751	20	28013.01	
3579.098	10	27932.03	$214357°_{3/2} - 242290_{3/2}$
3582.717	8	27903.81	$213311°_{7/2} - 241215_{9/2}$
3584.579	10	27889.32	$214357°_{3/2} - 242247_{3/2}$
3585.364	5	27883.21	$201215_{3/2} - 229098°_{7/2}$?
3588.221	2	27861.01	$214357°_{3/2} - 242219_{3/2}$
3589.005	10	27854.93	$238788°_{9/2} - 266643_{7/2}$
3593.553	25	27819.67	$238833°_{7/2} - 266653_{9/2}$?
3594.867	50h	27809.51	$238788°_{9/2} - 266597_{9/2}$
			$238833°_{7/2} - 266643_{7/2}$
3600.141	25	27768.77	$213025°_{5/2} - 240794_{3/2}$
3600.777	5	27763.86	$238833°_{7/2} - 266597_{9/2}$
3600.962	20h	27762.44	$216017°_{7/2} - 243780_{5/2}$
			$213311°_{7/2} - 241074_{7/2}$
3602.843	5	27747.94	$211821°_{7/2} - 239568_{9/2}$
3611.321	2	27682.80	$213311°_{7/2} - 240994_{5/2}$
3611.883	20	27678.50	$214328°_{7/2} - 242006_{5/2}$
3614.201	15	27660.74	$213311°_{7/2} - 240972_{9/2}$
3615.795	15	27648.55	$214357°_{3/2} - 242006_{5/2}$
3619.566	15	27619.75	$211821°_{7/2} - 239440_{7/2}$
3632.211	5	27523.59	$214766°_{5/2} - 242290_{5/2}$
3633.173	5	27516.31	$214702°_{5/2} - 242219_{3/2}$
3633.888	10	27510.89	$239142°_{11/2} - 266653_{9/2}$
3636.000	65	27494.91	$239142°_{11/2} - 266637_{11/2}$
3636.094	15	27494.20	$239148°_{5/2} - 266643_{7/2}$
3637.319	2	27484.94	
3639.420	100	27469.08	$211821°_{7/2} - 239290_{9/2}$
3641.256	5	27455.23	$239142°_{11/2} - 266597_{9/2}$
3641.598	3	27452.65	$214766°_{5/2} - 242219_{3/2}$
3645.893	3	27420.31	
3650.474	5	27385.90	$214702°_{5/2} - 242088_{7/2}$
3657.193	3	27335.59	$214357°_{3/2} - 241693_{5/2}$
3657.724	50	27331.62	$216448°_{3/2} - 243780_{5/2}$
3658.388	15	27326.66	$228423°_{5/2} - 255750_{3/2}$
3658.971	10	27322.30	$214766°_{5/2} - 242088_{7/2}$
3661.453	100	27303.78	$214702°_{5/2} - 242006_{5/2}$
3661.975	2	27299.89	$213025°_{5/2} - 240325_{5/2}$
3664.472	10	27281.29	$228468°_{3/2} - 255750_{3/2}$?
3664.511	5	27281.00	$228468°_{3/2} - 255750_{3/2}$
3669.195	50	27246.17	$238833°_{7/2} - 266079_{7/2}$
3673.455	75	27214.58	$216565°_{5/2} - 243780_{5/2}$
3675.872	2	27196.68	
3678.604	20	27176.49	$138982°_{7/2} - 166159_{9/2}$
3681.692	60	27153.69	$212415°_{9/2} - 239568_{9/2}$
3689.446	25	27096.63	
3689.660	15	27095.06	$142513°_{3/2} - 169608_{3/2}$
3690.151	20	27091.45	
3691.752	15	27079.70	
3694.662	75	27058.37	$215160°_{1/2} - 242219_{3/2}$
3694.766	10	27057.61	$142550°_{1/2} - 169608_{3/2}$
3696.693	5	27043.51	$212525°_{11/2} - 239568_{9/2}$
3697.557	200	27037.19	$213025°_{5/2} - 240062_{5/2}$
3698.035	75	27033.69	$214357°_{3/2} - 241391_{3/2}$
3698.452	3	27030.65	$223787_{3/2} - 250817°_{7/2}$
3699.154	60	27025.52	$212415°_{9/2} - 239440_{7/2}$
3700.000	10	27019.34	
3700.752	5	27013.85	$213311°_{7/2} - 240325_{5/2}$
3701.060	10	27011.60	
3701.811	20	27006.12	$215000°_{7/2} - 242006_{5/2}$
3702.920	500	26998.03	$211821°_{7/2} - 238818_{5/2}$
3703.921	50	26990.74	$214702°_{5/2} - 241693_{5/2}$
3706.757	40	26970.09	$214357°_{3/2} - 241328_{3/2}$
3708.538	8	26957.13	
3710.228	15	26944.86	$223787_{5/2} - 250731°_{5/2}$
3710.483	40	26943.00	$239148°_{5/2} - 266091_{5/2}$
3713.405	65	26921.80	$214328°_{7/2} - 241249_{7/2}$
3714.616	20	26913.03	
3715.037	400	26909.98	$211821°_{7/2} - 238730_{7/2}$
3715.705	3	26905.14	
3719.900	300	26874.80	$212415°_{9/2} - 239290_{9/2}$
3720.180	75	26872.78	$215417°_{5/2} - 242290_{5/2}$
3721.071	40	26866.34	$231333°_{5/2} - 258199_{7/2}$
3722.333	2	26857.23	
3726.167	75	26829.60	
3726.825	20	26824.86	$212415°_{9/2} - 239240_{11/2}$
3727.850	5	26817.49	$211821°_{7/2} - 238638_{7/2}$
3728.393	2	26813.58	
3730.041	5	26801.74	$215417°_{5/2} - 242219_{3/2}$
3730.693	10	26797.05	
3731.661	2	26790.10	$228960°_{5/2} - 255750_{3/2}$
3734.453	3	26770.07	
3735.201	75	26764.71	$212525°_{11/2} - 239290_{9/2}$
3735.597	5	26761.87	
3736.425	150	26755.94	$238788°_{9/2} - 265544_{11/2}$
3737.108	75	26751.05	$213311°_{7/2} - 240062_{5/2}$
3737.279	75	26749.83	$228423°_{5/2} - 255173_{7/2}$
3737.807	85	26746.05	$214328°_{7/2} - 241074_{7/2}$
3738.812	65	26738.86	$215160°_{1/2} - 241899_{1/2}$
3742.188	150	26714.74	$212525°_{11/2} - 239240_{11/2}$
3744.698	800	26696.83	$212415°_{9/2} - 239112_{11/2}$
3746.817	20	26681.74	
3748.266	400	26671.42	$215417°_{5/2} - 242088_{7/2}$
3748.956	5	26666.51	$214328°_{7/2} - 240994_{5/2}$
3749.657	2	26661.53	$214588°_{9/2} - 241249_{7/2}$
3750.370	10	26656.46	
3750.646	5	26654.50	
3752.056	600	26644.48	$214328°_{7/2} - 240972_{9/2}$
3753.166	75	26636.60	$214357°_{3/2} - 240994_{5/2}$
3754.480	200	26627.28	$214588°_{9/2} - 241215_{9/2}$
3754.759	50	26625.30	$214702°_{5/2} - 241328_{3/2}$
			$214766°_{5/2} - 241391_{3/2}$
3756.408	3	26613.61	
3759.424	100	26592.26	$216017°_{7/2} - 242610_{7/2}$
3760.056	25	26587.79	$229505°_{3/2} - 256093_{5/2}$
3760.215	150	26586.67	$212525°_{11/2} - 239112_{11/2}$
3760.734	15	26583.00	
3762.052	150	26573.69	$212995°_{9/2} - 239568_{9/2}$
3762.286	65	26572.03	
3763.762	5	26561.61	$214766°_{5/2} - 241328_{3/2}$
3763.992	100	26559.99	$232458°_{5/2} - 259018_{7/2}$
3765.014	10	26552.78	$231333°_{5/2} - 257885_{5/2}$
3765.840	20	26546.96	$214702°_{5/2} - 241249_{7/2}$
3768.729	50	26526.61	$228960°_{5/2} - 255486_{7/2}$
3770.928	15	26511.14	
3771.150	20	26509.58	
3771.523	100	26506.96	$215782°_{3/2} - 242290_{5/2}$
3771.878	2	26504.46	$238788°_{9/2} - 265292_{9/2}$?

TABLE 1. *Observed lines of Cu* III — Continued

λ (air)	Intensity	Wavenumber	Transition
3774.547	50	26485.72	$214588^{\circ}_{9/2} - 241074_{7/2}$
3774.793	50	26484.00	
3774.886	150	26483.34	$214766^{\circ}_{3/2} - 241249_{7/2}$
3776.971	1000	26468.72	$212525^{\circ}_{11/2} - 238994_{13/2}$
3778.344	100	26459.11	$238833^{\circ}_{7/2} - 265292_{9/2}$
			$211821^{\circ}_{7/2} - 238280_{9/2}$
3780.052	100	26447.15	$239142^{\circ}_{11/2} - 265589_{13/2}$
3781.561	75	26436.60	$214357^{\circ}_{3/2} - 240794_{3/2}$
3781.631	50	26436.11	$215782^{\circ}_{3/2} - 242219_{3/2}$
3782.520	5	26429.89	$142427^{\circ}_{5/2} - 168856_{5/2}$
3782.732	3	26428.41	$231457^{\circ}_{3/2} - 257885_{5/2}$
3784.030	100	26419.35	$232435^{\circ}_{7/2} - 258855_{9/2}$
3784.657	75	26414.97	$213025^{\circ}_{3/2} - 239440_{7/2}$
3785.914	10	26406.20	$214357^{\circ}_{3/2} - 240764_{1/2}$
3789.070	3	26384.21	$214588^{\circ}_{9/2} - 240972_{9/2}$
3790.798	800	26372.18	$214588^{\circ}_{9/2} - 240960_{11/2}$
3790.931	100	26371.26	$214702^{\circ}_{5/2} - 241074_{7/2}$
3792.486	85	26360.44	$229098^{\circ}_{7/2} - 255458_{9/2}$
3794.880	50	26343.81	$142513^{\circ}_{3/2} - 168856_{5/2}$
3798.931	65	26315.72	$212415^{\circ}_{9/2} - 238730_{7/2}$
3799.103	10	26314.53	
3801.009	100	26301.34	$213025^{\circ}_{3/2} - 239326_{3/2}$
3801.948	75	26294.84	$212995^{\circ}_{9/2} - 239290_{9/2}$
3802.385	5	26291.82	$214702^{\circ}_{5/2} - 240994_{5/2}$
3804.132	600	26279.75	$216017^{\circ}_{7/2} - 242297_{9/2}$
3807.414	300	26257.09	$213311^{\circ}_{7/2} - 239568_{9/2}$
3808.547	65	26249.28	$215000^{\circ}_{7/2} - 241249_{7/2}$
3809.175	600	26244.95	$212995^{\circ}_{9/2} - 239240_{11/2}$
3811.588	85	26228.34	$214766^{\circ}_{3/2} - 240994_{5/2}$
3812.012	5	26225.42	$228468^{\circ}_{3/2} - 254694_{3/2}$
3812.312	65	26223.36	$212415^{\circ}_{9/2} - 238638_{7/2}$
3813.519	300	26215.06	$215000^{\circ}_{7/2} - 241215_{9/2}$
3813.770	10	26213.33	$228960^{\circ}_{5/2} - 255173_{7/2}$
3815.218	3	26203.38	
3816.170	20	26196.85	$228423^{\circ}_{3/2} - 254620_{5/2}$
3820.473	20	26167.34	$215160^{\circ}_{1/2} - 241328_{3/2}$
3821.571	2	26159.83	
3822.800	3	26151.42	$228468^{\circ}_{3/2} - 254620_{5/2}$
3822.942	50	26150.44	$239142^{\circ}_{11/2} - 265292_{9/2}$
3826.089	100	26128.94	$213311^{\circ}_{7/2} - 239440_{7/2}$
3827.893	10	26116.62	$215782^{\circ}_{3/2} - 241899_{1/2}$
3831.531	85	26091.82	$214702^{\circ}_{5/2} - 240794_{3/2}$
3833.768	5	26076.60	
3834.022	50	26074.87	$229098^{\circ}_{7/2} - 255173_{7/2}$
3834.211	75	26073.59	$215000^{\circ}_{7/2} - 241074_{7/2}$
3838.525	100	26044.29	$216565^{\circ}_{5/2} - 242610_{7/2}$
3839.461	5	26037.94	
3840.894	20	26028.22	$214766^{\circ}_{3/2} - 240794_{3/2}$
3845.412	75	25997.64	$214328^{\circ}_{7/2} - 240325_{5/2}$
3845.937	15	25994.09	$215000^{\circ}_{7/2} - 240994_{5/2}$
3846.199	65	25992.32	
3846.720	3?	25988.80	$216017^{\circ}_{7/2} - 242006_{5/2}$
3848.292	20	25978.19	$213311^{\circ}_{7/2} - 239290_{9/2}$
3848.739	5	25975.17	$214328^{\circ}_{7/2} - 240303_{7/2}$
3848.859	15	25974.36	$215417^{\circ}_{5/2} - 241391_{3/2}$
3849.208	20	25972.00	$215000^{\circ}_{7/2} - 240972_{9/2}$
3849.845	65	25967.71	$214357^{\circ}_{3/2} - 240325_{5/2}$
3858.078	1	25912.29	
3858.305	60	25910.77	$215417^{\circ}_{5/2} - 241328_{3/2}$
3860.875	5	25893.52	
3864.866	10	25866.78	$240786^{\circ}_{7/2} - 266653_{9/2}$
3865.153	80	25864.86	$212415^{\circ}_{9/2} - 238280_{9/2}$
3866.390	40	25856.59	$240786^{\circ}_{7/2} - 266643_{7/2}$
3868.682	5	25841.27	$216448^{\circ}_{3/2} - 242290_{5/2}$
3869.158	1	25838.09	
3870.002	2	25832.46	$215417^{\circ}_{5/2} - 241249_{7/2}$
3873.200 [b]	50	25811.13	$240786^{\circ}_{7/2} - 266597_{9/2}$
3873.958	20	25806.08	
3874.790	40	25800.54	$240852^{\circ}_{9/2} - 266653_{9/2}$
3875.081	65	25798.60	$216448^{\circ}_{3/2} - 242247_{3/2}$
3875.244	10	25797.51	
3875.883	1	25793.26	$213025^{\circ}_{3/2} - 238818_{5/2}$
3877.197	75	25784.52	$240852^{\circ}_{9/2} - 266637_{11/2}$
3881.682	300	25754.73	$212525^{\circ}_{11/2} - 238280_{9/2}$
3883.169	8	25744.87	$240852^{\circ}_{9/2} - 266597_{9/2}$
3884.549 [b]	75	25735.72	$212995^{\circ}_{9/2} - 238730_{7/2}$
3884.772	30	25734.24	$228960^{\circ}_{5/2} - 254694_{3/2}$
3885.921	40	25726.63	
3887.702	200	25714.85	$214588^{\circ}_{9/2} - 240303_{7/2}$
3889.208	0	25704.89	$214357^{\circ}_{3/2} - 240062_{5/2}$
3890.799	20	25694.38	
3893.605	85	25675.86	$216017^{\circ}_{7/2} - 241693_{5/2}$
3894.203	10	25671.92	
3898.545	75	25643.33	$212995^{\circ}_{9/2} - 238638_{7/2}$
3901.662	25	25622.84	$214702^{\circ}_{5/2} - 240325_{5/2}$
3902.294	50	25618.69	
3903.222	100	25612.60	$213025^{\circ}_{3/2} - 238638_{7/2}$
3903.829	30	25608.62	$215782^{\circ}_{3/2} - 241391_{3/2}$
3904.651	3	25603.23	$215160^{\circ}_{1/2} - 240764_{1/2}$
3905.079	50	25600.42	$214702^{\circ}_{5/2} - 240303_{7/2}$
3908.611	10	25577.29	$215417^{\circ}_{5/2} - 240994_{5/2}$
3911.361	50	25559.31	$214766^{\circ}_{3/2} - 240325_{5/2}$
3911.578	20	25557.89	$216448^{\circ}_{3/2} - 242006_{5/2}$
3913.545	40	25545.05	$215782^{\circ}_{3/2} - 241328_{3/2}$
3914.802	15	25536.84	$214766^{\circ}_{3/2} - 240303_{7/2}$
3917.101	50	25521.86	$229098^{\circ}_{7/2} - 254620_{5/2}$
3928.168	40	25449.95	$232435^{\circ}_{7/2} - 257885_{5/2}$
3929.587	60	25440.76	$216565^{\circ}_{5/2} - 242006_{5/2}$
3932.931	40	25419.13	$213311^{\circ}_{7/2} - 238730_{7/2}$
3939.420	2	25377.26	$215417^{\circ}_{5/2} - 240794_{3/2}$
3940.397	1	25370.97	
3942.098	1	25360.02	$214702^{\circ}_{5/2} - 240062_{5/2}$
3947.284	100	25326.71	$213311^{\circ}_{7/2} - 238638_{7/2}$
3947.512	10	25325.24	$215000^{\circ}_{7/2} - 240325_{5/2}$
3949.572	60	25312.04	$142427^{\circ}_{5/2} - 167739_{7/2}$
3950.620	15	25305.32	$240786^{\circ}_{7/2} - 266091_{5/2}$
3951.022	100	25302.75	$215000^{\circ}_{7/2} - 240303_{7/2}$
3953.809	150	25284.91	$212995^{\circ}_{9/2} - 238280_{9/2}$
3960.072	50	25244.92	$216448^{\circ}_{3/2} - 241693_{5/2}$
3960.720	8	25240.79	$214328^{\circ}_{7/2} - 239568_{9/2}$
3962.877	15	25227.05	$240852^{\circ}_{9/2} - 266079_{7/2}$
3968.852	20	25189.08	$229505^{\circ}_{3/2} - 254694_{3/2}$
3978.532	100	25127.79	$216565^{\circ}_{5/2} - 241693_{5/2}$
3980.574	15	25114.90	$229505^{\circ}_{3/2} - 254620_{5/2}$
3980.930	30	25112.66	$214328^{\circ}_{7/2} - 239440_{7/2}$
3988.923	10	25062.34	$215000^{\circ}_{7/2} - 240062_{5/2}$
4008.025	10	24942.89	$216448^{\circ}_{3/2} - 241391_{3/2}$
4011.858	15	24919.06	$142820^{\circ}_{7/2} - 167739_{7/2}$
4013.577	10	24908.39	$215417^{\circ}_{3/2} - 240325_{3/2}$
4019.430	15	24872.12	
4037.268	5	24762.23	$216565^{\circ}_{5/2} - 241328_{3/2}$
4039.580	10	24748.06	$234654_{9/2} - 259402^{\circ}_{9/2}$
4041.242	30	24737.88	$214702^{\circ}_{5/2} - 239440_{7/2}$
4050.073	2	24683.94	$216565^{\circ}_{5/2} - 241249_{7/2}$
4051.651	30	24674.33	$214766^{\circ}_{3/2} - 239440_{7/2}$
4059.889	40	24624.26	$214702^{\circ}_{5/2} - 239326_{3/2}$
4069.123	10	24568.38	$215000^{\circ}_{7/2} - 239568_{9/2}$
4070.395	20	24560.70	$214766^{\circ}_{3/2} - 239326_{3/2}$
4072.843	30	24545.94	$216448^{\circ}_{3/2} - 240994_{5/2}$
4078.337	15	24512.88	
4090.487	100	24440.07	$215000^{\circ}_{7/2} - 239440_{7/2}$
			$240852^{\circ}_{9/2} - 265292_{9/2}$
4092.376	2	24428.79	$216565^{\circ}_{5/2} - 240994_{5/2}$
4096.722	3	24402.87	$214328^{\circ}_{7/2} - 238730_{7/2}$
4106.327	30	24345.79	$216448^{\circ}_{3/2} - 240794_{3/2}$?
4112.299	10	24310.44	$214328^{\circ}_{7/2} - 238638_{7/2}$
4125.237	10	24234.19	
4149.236	2	24094.03	
4186.957	15	23876.97	$216448^{\circ}_{3/2} - 240325_{5/2}$
			$210159_{5/2} - 234036^{\circ}_{3/2}$
4187.807	10	23872.12	$214766^{\circ}_{5/2} - 238638_{7/2}$
4191.723	5	23849.82	$234036^{\circ}_{3/2} - 257885_{5/2}$
4197.252	2	23818.40	$215000^{\circ}_{7/2} - 238818_{5/2}$
4212.301	20	23733.31	$215100_{5/2} - 238833^{\circ}_{7/2}$
4232.447	8	23620.34	$210033_{3/2} - 233653^{\circ}_{3/2}$
4246.192	20	23543.88	$144195^{\circ}_{5/2} - 167739_{7/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (air)	Intensity	Wavenumber	Transition
4253.549	2	23503.16	$145353°_{3/2} - 168856_{5/2}$
4270.654	8	23409.03	$243234°_{7/2} - 266643_{7/2}$?
4283.400	200	23339.37	$142820°_{7/2} - 166159_{9/2}$
4286.475	3	23322.63	
4286.800	2	23320.86	
4298.294	10	23258.50	
4313.014	3	23179.12	
4313.330	100	23177.42	$234490°_{5/2} - 257668_{7/2}$
4313.661	100	23175.65	$234427°_{3/2} - 257602_{3/2}$
4316.650	3	23159.60	
4318.034	2	23152.18	
4318.313	1	23150.68	
4318.537	30	23149.48	
4321.522	2	23133.49	
4323.742	15	23121.61	
4325.539	2	23112.01	$234490°_{5/2} - 257602_{3/2}$
4326.118	2	23108.91	$236323°_{1/2} - 259432_{3/2}$
4328.657	8	23095.36	$211679_{5/2} - 334775°_{5/2}$?
4332.157	2	23076.70	
4332.909	20	23072.70	$250734°_{9/2} - 273807_{9/2}$
4333.011	10	23072.15	$234530°_{1/2} - 257602_{3/2}$
4333.574	3	23069.16	
4334.927	100	23061.95	$234427°_{3/2} - 257488_{5/2}$
4335.276	5	23060.10	
4335.787	20	23057.38	
4337.486	15	23048.35	
4338.221	2	23044.44	
4339.663	100	23036.78	
4341.874	10	23025.06	
4342.065	100	23024.04	$234490°_{5/2} - 257514_{7/2}$
4343.016	0	23019.00	
4343.490	2	23016.49	
4344.139	5	23013.05	
4344.339	100	23011.99	$234562°_{7/2} - 257574_{9/2}$
4344.466	100	23011.32	$234660°_{3/2} - 257671_{5/2}$
4345.004	50	23008.47	$236471°_{5/2} - 259479_{7/2}$
4345.203	30	23007.42	$234532°_{13/2} - 257540_{13/2}$
4346.038	40	23003.00	$234537°_{15/2} - 257540_{15/2}$
4346.827	20	22998.82	$236471°_{5/2} - 259470_{5/2}$
4346.936	20	22998.24	$234490°_{5/2} - 257488_{5/2}$
4348.576	2	22989.57	$250817°_{7/2} - 273807_{9/2}$
4348.736	10	22988.73	
4349.099	150	22986.81	$236417°_{13/2} - 259404_{13/2}$
4349.331	50?	22985.58	$236418°_{11/2} - 259404_{11/2}$
4349.751	1	22983.36	
4349.849	3	22982.84	$250817°_{7/2} - 273800_{7/2}$
4350.746	20	22978.10	
4351.834	50	22972.36	
4351.971	500	22971.64	$234532°_{13/2} - 257504_{15/2}$
4352.219	5	22970.33	
4352.451	3?	22969.10	
4352.798	1000	22967.27	$234537°_{15/2} - 257504_{17/2}$
4353.308	3	22964.58	$234530°_{1/2} - 257495_{1/2}$
4354.525	10	22958.16	$237674°_{5/2} - 260632_{7/2}$
4355.237	500	22954.41	$236417°_{13/2} - 259372_{15/2}$
4355.478	200	22953.14	$236418°_{11/2} - 259371_{13/2}$
4355.569	100	22952.66	$234562°_{7/2} - 257514_{7/2}$
4356.079	300	22949.97	$237641°_{11/2} - 260591_{13/2}$
4356.750	300	22946.44	$237644°_{9/2} - 260590_{11/2}$
4356.975	3	22945.25	
4358.163	3	22939.00	$209875_{5/2} - 232814°_{3/2}$
4358.530	10	22937.07	
4360.148	30	22928.56	$261169°_{13/2} - 254098°_{15/2}$?
4360.346	100	22927.52	$261167°_{15/2} - 284095_{17/2}$?
4361.862	15	22919.55	$234654°_{9/2} - 257574_{9/2}$
4362.735	3	22914.96	
4362.989	10	22913.63	$216235_{3/2} - 239148°_{5/2}$
4363.244	30	22912.29	$211123_{3/2} - 234036°_{3/2}$
4364.226	2	22907.13	
4364.565	20	22905.35	
4366.186	200	22896.85	$234775°_{5/2} - 257671_{5/2}$
4366.690	20	22894.21	$234670°_{13/2} - 257565_{13/2}$
4367.247	100	22891.29	$236511°_{7/2} - 259402_{9/2}$
4368.318	75	22885.68	$236531°_{11/2} - 259417_{11/2}$
4369.314	75	22880.46	$236537°_{9/2} - 259417_{11/2}$
4369.438	75	22879.81	$236590°_{3/2} - 259470_{5/2}$
4370.126	300	22876.21	$234654°_{9/2} - 257530_{11/2}$
4370.344	300	22875.07	$234681°_{11/2} - 257556_{11/2}$
4370.841	500	22872.46	$236531°_{11/2} - 259404_{13/2}$
4371.395	500	22869.57	$234670°_{13/2} - 257540_{15/2}$
4371.878	200	22867.04	$237778°_{9/2} - 260646_{11/2}$
4372.167	5	22865.53	$236537°_{9/2} - 259402_{9/2}$
4372.446	5	22864.07	
4372.864	75	22861.88	$237814°_{7/2} - 260676_{9/2}$
4373.429	500	22858.93	$234681°_{11/2} - 257540_{13/2}$
			$234812°_{7/2} - 257671_{5/2}$
4374.154	10	22855.14	$234812°_{7/2} - 257668_{7/2}$
4374.398	50	22853.87	$236550°_{9/2} - 259404_{11/2}$
4374.682	5	22852.38	$236550°_{9/2} - 259402_{9/2}$
4374.984	3	22850.81	$234774°_{9/2} - 257625_{9/2}$
4375.432	300	22848.47	$234716°_{11/2} - 257565_{13/2}$
4376.243	5	22844.23	
4376.649	15	22842.11	$236590°_{3/2} - 259432_{3/2}$
4377.113	1000	22839.69	$234716°_{11/2} - 257556_{11/2}$
4378.064	75	22834.73	$234660°_{3/2} - 257495_{1/2}$
4378.991	10	22829.90	
4379.309	5	22828.24	$234660°_{3/2} - 257488_{5/2}$?
4381.002	3	22819.42	
4381.290	5	22817.92	$237814°_{7/2} - 260632_{7/2}$?
4382.026	100	22814.08	$234716°_{11/2} - 257530_{11/2}$
4382.314	300	22812.58	$234812°_{7/2} - 257625_{9/2}$
			$189602_{7/2} - 212415°_{9/2}$
4382.686	10	22810.65	
4384.351	50	22801.99	$237830°_{5/2} - 260632_{7/2}$
4384.561	100	22800.89	$250999°_{9/2} - 273800_{7/2}$
4384.768	20	22799.82	$214844_{7/2} - 237644°_{9/2}$?
4385.397	150	22796.55	$251010°_{11/2} - 273807_{9/2}$
4386.077	20	22793.01	
4386.333	50	22791.68	$251010°_{11/2} - 273802_{13/2}$
4386.425	200	22791.21	$236611°_{7/2} - 259402_{9/2}$
4388.256	200?	22781.70	$234774°_{9/2} - 257556_{11/2}$
4389.123	100	22777.20	
4390.258	5	22771.31	
4391.488	5	22764.93	
4396.147	30	22740.80	
4396.499	50	22738.98	$250999°_{9/2} - 273738_{9/2}$
4399.732	75	22722.27	$251010°_{11/2} - 273732_{11/2}$
4403.499	5	22702.84	
4408.235	15	22678.45	
4409.880	30	22669.99	
4417.191	2	22632.47	
4418.324	5	22626.66	
4418.977	2	22623.32	
4438.030	3	22526.20	
4453.330	2	22448.81	$194117_{7/2} - 216565°_{5/2}$
4568.621	5	21882.31	$194683_{3/2} - 216565°_{5/2}$
4621.943	10	21629.86	$193370_{9/2} - 215000°_{7/2}$
4724.409	30	21160.75	
4741.343	30	21085.17	$212951_{5/2} - 234036°_{3/2}$
4745.291	4	21067.63	$193520_{7/2} - 214588°_{9/2}$
4781.271	30	20909.09	$213127_{3/2} - 234036°_{3/2}$
4784.813	10	20893.62	$195555_{5/2} - 216448°_{3/2}$
4787.148	5	20883.43	$194117_{7/2} - 215000°_{7/2}$
4806.435	1	20799.63	
4834.873	3	20677.29	$195340_{5/2} - 216017°_{7/2}$
4839.333	10	20658.23	
4841.423	25	20649.31	$194117_{7/2} - 214766°_{5/2}$
4856.428	8	20585.52	$194117_{7/2} - 214702°_{5/2}$
4857.135	10	20582.52	
4863.626	5	20555.05	$194033_{11/2} - 214588°_{9/2}$
4883.553	30	20471.18	$194117_{7/2} - 214588°_{9/2}$
4885.570	15	20462.73	$195555_{5/2} - 216017°_{7/2}$
4927.410	150	20288.97	$220563_{9/2} - 240852°_{9/2}$
4928.792	10	20283.28	$220569_{7/2} - 240852°_{9/2}$
4944.952	120	20217.00	$220569_{7/2} - 240786°_{7/2}$

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TABLE 1. *Observed lines of Cu* III—Continued

λ (air)	Intensity	Wavenumber	Transition
4946.455	10	20210.86	$194117_{7/2} - 214328°_{7/2}$
4967.901	10	20123.61	$196442_{3/2} - 216565°_{3/2}$
4996.988	5	20006.47	$196442_{3/2} - 216448°_{3/2}$
5001.366	20	19988.96	$196028_{9/2} - 216017°_{7/2}$
5005.202	6	19973.64	$213312_{3/2} - 233285°_{5/2}$
5008.721	4	19959.61	$234660°_{3/2} - 254620_{5/2}$?
5020.148	3	19914.18	
5033.291	40	19862.18	$195555_{5/2} - 215417°_{5/2}$
5045.966	8	19812.29	
5056.710	2	19770.19	
5070.133	20	19717.85	$196730_{5/2} - 216448°_{3/2}$
5078.970	10	19683.54	$212752_{7/2} - 232435°_{7/2}$
5085.023	15	19660.11	$195340_{5/2} - 215000°_{7/2}$
5085.910	15	19656.69	$195343_{7/2} - 215000°_{7/2}$
5092.762	70	19630.24	$209875_{5/2} - 229505°_{3/2}$
5094.282	400	19624.38	$193370_{9/2} - 212995°_{9/2}$
5124.894	5	19507.16	$212951_{5/2} - 232458°_{5/2}$
5125.476	5	19504.95	$193520_{7/2} - 213025°_{5/2}$
5130.731	150	19484.97	$212951_{5/2} - 232435°_{7/2}$
5133.512	40	19474.42	$193520_{7/2} - 212995°_{9/2}$
5134.104	20	19472.17	$210033_{3/2} - 229505°_{3/2}$
5134.606	3	19470.27	$213815_{7/2} - 233285°_{5/2}$
5141.185	20	19445.35	$195555_{5/2} - 215000°_{7/2}$
5147.218	15	19422.56	$195343_{7/2} - 214766°_{5/2}$
5156.097	5	19389.11	$214264_{3/2} - 233653°_{3/2}$
5164.119	15	19358.99	$195343_{7/2} - 214702°_{5/2}$
5168.967	200	19340.84	$196442_{3/2} - 215782°_{3/2}$
5171.584	40	19331.05	$213127_{3/2} - 232458°_{5/2}$
5175.332	2	19317.05	$196100_{3/2} - 215417°_{5/2}$
5178.367	1	19305.73	
5179.271	8	19302.36	$213133_{5/2} - 232435°_{7/2}$
5194.846	15	19244.49	$195343_{7/2} - 214588°_{9/2}$
5198.108	10	19232.41	
5200.561	150	19223.34	$209875_{5/2} - 229098°_{7/2}$
5200.876	30	19222.18	$196795_{9/2} - 216017°_{7/2}$
5203.670	200	19211.86	$195788_{7/2} - 215000°_{7/2}$
5203.839	150	19211.23	$195555_{5/2} - 214766°_{5/2}$
5208.338	400	19194.64	$194117_{7/2} - 213311°_{7/2}$
5216.231	250	19165.59	$197400_{5/2} - 216565°_{5/2}$
5219.213	600	19154.64	$193370_{9/2} - 212525°_{11/2}$
5221.113	80	19147.67	$195555_{5/2} - 214702°_{5/2}$
5221.608	20	19145.86	$213312_{3/2} - 232458°_{5/2}$
5223.070	2	19140.50	$193885_{5/2} - 213025°_{5/2}$
5241.473	15	19073.30	
5244.986	3	19060.52	$196100_{3/2} - 215160°_{1/2}$
5248.300	150	19048.49	$197400_{5/2} - 216448°_{3/2}$
5249.407	250	19044.47	$193370_{9/2} - 212415°_{9/2}$
5255.753	60	19021.47	$214264_{3/2} - 233285°_{5/2}$
5255.960	10	19020.73	$210033_{3/2} - 229054°_{1/2}$
5256.834	15	19017.56	$195340_{5/2} - 214357°_{3/2}$
5263.989	5	18991.71	$221861_{7/2} - 240852°_{9/2}$
5265.117	5	18987.65	$195340_{5/2} - 214328°_{7/2}$
5267.877	30?	18977.70	$195788_{7/2} - 214766°_{5/2}$
5268.588	200	18975.14	$196442_{3/2} - 215417°_{3/2}$
5269.504	10	18971.84	$196028_{9/2} - 215000°_{7/2}$
5272.262	50	18961.91	$194033_{11/2} - 212995°_{9/2}$
5278.538	3	18939.37	$210159_{5/2} - 229098°_{7/2}$
5282.018	100	18926.89	$210033_{3/2} - 228960°_{5/2}$
5283.033	5	18923.25	$214730_{1/2} - 233653°_{3/2}$
5285.578	150	18914.14	$195788_{7/2} - 214702°_{5/2}$
5287.136	250	18908.57	$194117_{7/2} - 213025°_{5/2}$
5291.071	7	18894.51	$193520_{7/2} - 212415°_{9/2}$
5295.689	200	18878.03	$194117_{7/2} - 212995°_{9/2}$
5301.165	15	18858.53	$210239_{7/2} - 229098°_{7/2}$
5309.107	100	18830.32	$195757_{11/2} - 214588°_{9/2}$
5314.957	10	18809.59	$195518_{9/2} - 214328°_{7/2}$
5316.862	150	18802.86	$195555_{5/2} - 214357°_{3/2}$
5317.778	400	18799.62	$195788_{7/2} - 214588°_{9/2}$
5325.344	250	18772.91	$195555_{5/2} - 214328°_{7/2}$
5337.864	75	18728.88	$220413_{13/2} - 239142°_{11/2}$
5340.362	2	18720.12	$210239_{7/2} - 228960°_{5/2}$
5340.798	60	18718.59	$196442_{3/2} - 215160°_{1/2}$
5356.064	20	18665.24	$197900_{3/2} - 216565°_{5/2}$
5362.793	5	18641.82	$197375_{9/2} - 216017°_{7/2}$
5364.709	15	18635.16	$195722_{1/2} - 214357°_{3/2}$
5369.794	300	18617.51	$197400_{5/2} - 216017°_{7/2}$
5374.114	20	18602.55	$196100_{3/2} - 214702°_{5/2}$
5376.665	15	18593.72	$209875_{5/2} - 228468°_{3/2}$
5380.443	15	18580.66	$212752_{7/2} - 231333°_{5/2}$
5380.826	25	18579.34	$220569_{7/2} - 239148°_{5/2}$
5381.044	100	18578.59	$220563_{9/2} - 239142°_{11/2}$
5386.560	3	18559.56	$196028_{9/2} - 214588°_{9/2}$
5389.417	25	18549.72	$214264_{3/2} - 232814°_{3/2}$
5389.812	75	18548.37	$209875_{5/2} - 228423°_{5/2}$
5391.703	3	18541.86	
5392.431	25	18539.36	$195788_{7/2} - 214328°_{7/2}$
5402.013	15	18506.47	$212951_{5/2} - 231457°_{3/2}$
5402.584	10	18504.52	$198061_{5/2} - 216565°_{5/2}$
5410.669	40	18476.87	$220311_{11/2} - 238788°_{9/2}$
5418.485	350	18450.21	$193370_{9/2} - 211821°_{7/2}$
5422.762	20	18435.66	$210033_{3/2} - 228468°_{3/2}$
5428.839	15	18415.03	$198033_{1/2} - 216448°_{3/2}$
5429.566	5	18412.56	
5437.001	3	18387.38	$198061_{5/2} - 216448°_{3/2}$
5438.602	200	18381.97	$212951_{5/2} - 231333°_{5/2}$
5438.602	200	18381.97	$194033_{11/2} - 212415°_{9/2}$
5444.480	2	18362.12	$197055_{7/2} - 215417°_{5/2}$
5447.050	3h	18353.46	
5450.455	50	18341.99	$194683_{3/2} - 213025°_{5/2}$
5453.893	10	18330.43	$213127_{3/2} - 231457°_{3/2}$
5455.842	15	18323.88	$213133_{3/2} - 231457°_{3/2}$
5459.735	5	18310.82	
5460.065	15	18309.71	$210159_{3/2} - 228468°_{3/2}$
5462.888	50	18300.25	$193520_{7/2} - 211821°_{7/2}$
5463.161	10	18299.34	$196028_{9/2} - 214328°_{7/2}$
5463.548	250	18298.04	$194117_{7/2} - 212415°_{9/2}$
5471.976	50	18269.86	$220563_{9/2} - 238833°_{7/2}$
5473.322	0	18265.36	
5473.617	2	18264.38	$220569_{7/2} - 238833°_{7/2}$ $210159_{5/2} - 228423°_{5/2}$
5475.494	15	18258.12	$196742_{7/2} - 215000°_{7/2}$
5475.593	5	18257.79	$196100_{3/2} - 214357°_{3/2}$
5477.959	5	18249.90	$195061_{9/2} - 213311°_{7/2}$
5485.687	1	18224.19	$220563_{9/2} - 238788°_{9/2}$
5487.355	50	18218.65	$220569_{7/2} - 238788°_{9/2}$
5491.169	1	18206.00	$213127_{3/2} - 231333°_{5/2}$
5494.937	250	18193.52	$214264_{3/2} - 232458°_{5/2}$ $194331_{13/2} - 212525°_{11/2}$
5497.951	15	18183.54	$210239_{7/2} - 228423°_{5/2}$
5499.985	50	18176.82	$194818_{11/2} - 212995°_{9/2}$
5516.648	5	18121.92	
5520.010	2	18110.88	
5520.825	15h	18108.20	
5523.027	5	18100.99	
5542.045	10	18038.87	
5543.062	15	18035.56	$196730_{5/2} - 214766°_{5/2}$
5544.821	1	18029.84	$236590°_{3/2} - 254620_{5/2}$?
5546.619	5	18023.99	$196742_{7/2} - 214766°_{5/2}$
5548.757	3	18017.05	$197400_{5/2} - 215417_{5/2}$
5552.618	15w	18004.52	
5558.267	10	17986.22	$213312_{3/2} - 231298°_{1/2}$
5558.950	2	17984.01	
5559.990	3	17980.65	
5562.667	0	17972.00	$196730_{5/2} - 214702°_{5/2}$
5562.861	3	17971.37	$195340_{5/2} - 213311°_{7/2}$
5563.904	30	17968.00	$195343_{7/2} - 213311°_{7/2}$
5566.035	10	17961.12	$197199_{1/2} - 215160°_{1/2}$
5566.258	25	17960.40	$196742_{7/2} - 214702°_{5/2}$
5570.945	20	17945.29	$197055_{7/2} - 215000°_{7/2}$
5571.920	3	17942.15	
5573.938	50	17935.66	$193885_{5/2} - 211821°_{7/2}$
5574.680	5	17933.27	$195061_{9/2} - 212995°_{9/2}$
5575.634	10	17930.20	$211123_{3/2} - 229054°_{1/2}$
5580.05	1	17916.01	$196442_{3/2} - 214357°_{3/2}$
5586.11	1	17896.58	$196806_{3/2} - 214702°_{5/2}$
5587.837	5	17891.04	$216145_{5/2} - 234036°_{3/2}$

TABLE 1. *Observed lines of Cu* III—Continued

λ (air)	Intensity	Wavenumber	Transition
5590.526	10	17882.44	$197900\ _{5/2} - 215782°_{3/2}$
5591.179	5h	17880.35	$213418\ _{1/2} - 231298°_{1/2}$
5597.190	2	17861.15	
5598.120	3	17858.18	
5599.646	5	17853.31	$211652\ _{3/2} - 229505°_{3/2}$
5601.900	2	17846.13	$215807\ _{3/2} - 233653°_{3/2}$
5603.278	5	17841.74	
5604.96	1	17836.39	$211123\ _{3/2} - 228960°_{5/2}$?
5607.410	2	17828.60	
5608.315	10	17825.72	$211679\ _{5/2} - 229505°_{3/2}$
5609.001	100	17823.54	$197593\ _{7/2} - 215417°_{5/2}$
5610.517	15	17818.72	
5617.246	10	17797.38	$197985\ _{3/2} - 215782°_{3/2}$
5618.526	50	17793.32	$195518\ _{9/2} - 213311°_{7/2}$
5618.701	0	17792.77	$196795\ _{9/2} - 214588°_{9/2}$
5621.237	50	17784.74	$211313\ _{9/2} - 229098°_{7/2}$
5622.78	1	17779.86	
5628.116	2	17763.00	$223089\ _{9/2} - 240852°_{9/2}$
5628.336	1	17762.31	
5630.125	5	17756.67	$195555\ _{3/2} - 213311°_{7/2}$
5636.900	5	17735.32	$237751°_{7/2} - 255486\ _{7/2}$
5637.691	5	17732.84	
5641.230	20	17721.71	$198061\ _{5/2} - 215782°_{3/2}$
5643.747	3	17713.81	$215100\ _{5/2} - 232814°_{3/2}$
5644.595	30	17711.15	$197055\ _{7/2} - 214766°_{5/2}$
5645.925	50	17706.97	$194818\ _{11/2} - 212525°_{11/2}$
5649.232	10	17696.61	$223089\ _{9/2} - 240786°_{7/2}$
5651.762	20	17688.69	$211271\ _{7/2} - 228960°_{5/2}$
5652.001	30	17687.94	$214747\ _{9/2} - 232435°_{7/2}$
5652.847	20	17685.29	$195340\ _{5/2} - 213025°_{5/2}$
5653.923	10	17681.93	$195343\ _{7/2} - 213025°_{5/2}$
5655.292	10	17677.65	$223175\ _{11/2} - 240852°_{9/2}$
5663.529	10	17651.94	$223200\ _{9/2} - 240852°_{9/2}$
5668.876	50	17635.29	$198930\ _{7/2} - 216565°_{5/2}$
5671.494	10	17627.15	$196730\ _{5/2} - 214357°_{3/2}$
5672.310	50	17624.61	$197375\ _{9/2} - 215000°_{7/2}$
5676.005	30	17613.14	$214844\ _{7/2} - 232458°_{5/2}$
5676.329	5	17612.13	$223174\ _{7/2} - 240786°_{7/2}$
5680.160	1	17600.25	$197400\ _{5/2} - 215000°_{7/2}$
5681.262	30	17596.84	$194818\ _{11/2} - 212415°_{9/2}$
5684.886	20	17585.62	$196742\ _{7/2} - 214328°_{7/2}$
			$223200\ _{9/2} - 240786°_{7/2}$
5696.563	150	17549.58	$197038\ _{11/2} - 214588°_{9/2}$
5700.593	5	17537.17	
5702.116	75	17532.48	$196795\ _{9/2} - 214328°_{7/2}$
5705.140	3	17523.19	$195788\ _{7/2} - 213311°_{7/2}$
5707.251	15	17516.71	$197900\ _{5/2} - 215417°_{5/2}$
5716.420	20	17488.61	$214989\ _{3/2} - 232478°_{3/2}$
5720.313	30	17476.71	$195518\ _{9/2} - 212995°_{9/2}$
5722.340	1	17470.52	$195555\ _{3/2} - 213025°_{5/2}$
5722.990	2	17468.54	$214989\ _{5/2} - 232458°_{5/2}$
5724.651	10	17463.47	$195061\ _{9/2} - 212525°_{11/2}$
5735.070	2	17431.74	$197985\ _{3/2} - 215417°_{5/2}$
5736.830	2	17426.40	
5739.440	3	17418.47	$216235\ _{3/2} - 233653°_{3/2}$?
			$211679\ _{5/2} - 229098°_{7/2}$?
5760.050	10	17356.15	$198061\ _{5/2} - 215417°_{5/2}$
5760.987	75	17353.32	$195061\ _{9/2} - 212415°_{9/2}$
5763.790	5	17344.88	$211123\ _{3/2} - 228468°_{3/2}$
5764.848	0	17341.70	
5765.091	5	17340.97	$122860\ _{1/2} - 140201°_{3/2}$
5768.564	100	17330.53	$198687\ _{9/2} - 216017°_{7/2}$
5775.730	15	17309.03	$215976\ _{7/2} - 233285°_{5/2}$
5783.110	3	17286.94	
5784.400	10	17283.08	$196028\ _{9/2} - 213311°_{7/2}$
5785.310	2	17280.37	$211679\ _{5/2} - 228960°_{5/2}$
5788.830	2	17269.86	$221878\ _{3/2} - 239148°_{5/2}$
5797.775	10	17243.21	$224450°_{7/2} - 241693\ _{3/2}$
5799.819	75	17237.14	$195788\ _{7/2} - 213025°_{5/2}$
			$195757\ _{11/2} - 212995°_{9/2}$
5802.320	5	17229.71	
5808.152	50	17212.41	$197375\ _{9/2} - 214588°_{9/2}$
5810.155	10	17206.47	$195788\ _{7/2} - 212995°_{9/2}$
5814.720	3	17192.97	$214264\ _{3/2} - 231457°_{3/2}$
5818.140	10	17182.86	$211286\ _{1/2} - 228468°_{3/2}$
5820.763	100	17175.12	$197985\ _{3/2} - 215160°_{1/2}$
5821.58	2	17172.71	$197593\ _{7/2} - 214766°_{5/2}$
5828.55	30	17152.17	$211271\ _{7/2} - 228423°_{5/2}$
5837.05	0	17127.19	$198033\ _{1/2} - 215160°_{1/2}$
5846.32	5	17100.04	$197900\ _{5/2} - 215000°_{7/2}$
5847.29	2h	17097.20	
5850.72	100	17087.18	$198930\ _{7/2} - 216017°_{7/2}$
5856.13	50	17071.39	$195343\ _{7/2} - 212415°_{9/2}$
5867.85	3	17037.29	
5878.32	5h	17006.95	$195518\ _{9/2} - 212525°_{11/2}$
			$215807\ _{3/2} - 232814°_{3/2}$
5890.22	15	16972.59	$221861\ _{7/2} - 238833°_{7/2}$
5892.36	30	16966.43	$196028\ _{9/2} - 212995°_{9/2}$
5895.32	30	16957.91	$197400\ _{5/2} - 214357°_{3/2}$
5901.82	3	16939.23	$198061\ _{5/2} - 215000°_{7/2}$
5905.78	10	16927.87	$197400\ _{5/2} - 214328°_{7/2}$
5909.73	10	16916.56	
5916.71	75	16896.60	$195518\ _{9/2} - 212415°_{9/2}$
5948.37	1	16806.67	
5949.93	50	16802.27	$197900\ _{5/2} - 214702°_{5/2}$
5960.82	10	16771.57	$211652\ _{3/2} - 228423°_{5/2}$
5962.29	5	16767.43	$195757\ _{11/2} - 212525°_{11/2}$
5965.25	200	16759.11	$195061\ _{9/2} - 211821°_{7/2}$
5970.68	5	16743.87	$211679\ _{5/2} - 228423°_{5/2}$
5974.06	15	16734.40	$197593\ _{7/2} - 214328°_{7/2}$
5980.18	5	16717.27	$197985\ _{3/2} - 214702°_{5/2}$
5984.53	15	16705.12	$198061\ _{5/2} - 214766°_{5/2}$
5997.40	1	16669.27	$216145\ _{3/2} - 232814°_{3/2}$
5998.99	5	16664.86	
6001.72	50	16657.28	$195757\ _{11/2} - 212415°_{9/2}$
6007.34	5	16641.69	$198061\ _{5/2} - 214702°_{5/2}$
6012.79	3	16626.61	$195788\ _{7/2} - 212415°_{9/2}$
6029.30	30	16581.08	$196730\ _{5/2} - 213311°_{7/2}$?
6030.04	2h	16579.05	$216235\ _{3/2} - 232814°_{3/2}$
6033.45	15	16569.68	$196742\ _{7/2} - 213311°_{7/2}$
6060.14	1	16496.70	$196028\ _{9/2} - 212525°_{11/2}$
6063.29	0	16488.13	$214844\ _{7/2} - 231333°_{5/2}$
6063.77	1	16486.83	$198930\ _{7/2} - 215417°_{5/2}$
6066.07	30	16480.57	$195340\ _{5/2} - 211821°_{7/2}$
6067.30	10	16477.23	$195343\ _{7/2} - 211821°_{7/2}$
6070.73	1	16467.92	$214989\ _{3/2} - 231457°_{3/2}$
6076.43	2	16452.48	
6085.63	3	16427.60	$197900\ _{5/2} - 214328°_{7/2}$
6095.30	15	16401.54	
6095.64	20	16400.63	$122860\ _{1/2} - 139261°_{1/2}$
6100.87	30	16386.57	$196028\ _{9/2} - 212415°_{9/2}$
6106.13	15	16372.45	$197985\ _{3/2} - 214357°_{3/2}$
6111.85	1	16357.13	$215100\ _{5/2} - 231457°_{3/2}$
6132.31	30	16302.56	$195518\ _{9/2} - 211821°_{7/2}$
6134.51	20	16296.71	$198061\ _{5/2} - 214357°_{3/2}$
6135.16	10	16294.98	$196730\ _{5/2} - 213025°_{5/2}$
6145.79	5	16266.80	$198061\ _{5/2} - 214328°_{7/2}$
6173.75	1	16193.13	$213312\ _{3/2} - 229505°_{3/2}$
6227.78	1	16052.65	$223089\ _{9/2} - 239142°_{11/2}$
6235.66	2	16032.36	$195788\ _{7/2} - 211821°_{7/2}$
6251.94	2	15990.61	$213514\ _{3/2} - 229505°_{3/2}$
6255.80	2h	15980.75	$216833\ _{1/2} - 232814°_{3/2}$
6258.23	15	15974.54	$223174\ _{7/2} - 239148°_{5/2}$
6259.80	20	15970.53	$197055\ _{7/2} - 213025°_{5/2}$
6261.08	30	15967.27	$223175\ _{11/2} - 239142°_{11/2}$
6265.28	10	15956.56	$197038\ _{11/2} - 212995°_{9/2}$
6270.31	1	15943.76	
6271.17	15	15941.58	$223200\ _{9/2} - 239142°_{11/2}$
6316.40	2	15827.43	
6330.41	5	15792.40	$196028\ _{9/2} - 211821°_{7/2}$
6349.91	3	15743.90	$223089\ _{9/2} - 238833°_{7/2}$
6360.33	2	15718.11	$197593\ _{7/2} - 213311°_{7/2}$
6368.35	30	15698.31	$223089\ _{9/2} - 238788°_{9/2}$
6369.27	50	15696.05	$215761\ _{1/2} - 231457°_{3/2}$
6383.30	3	15661.55	
6383.64	1	15660.71	

TABLE 1. *Observed lines of Cu* III—Continued

λ (air)	Intensity	Wavenumber	Transition	λ (air)	Intensity	Wavenumber	Transition
6387.87	3	15650.34	$215807\ _{3/2} - 231457°_{3/2}$	6541.47	1	15282.86	$213815\ _{7/2} - 229098°_{7/2}$
6391.69	15	15640.99	$198687\ _{9/2} - 214328°_{7/2}$	6582.32	10	15188.02	$216145\ _{5/2} - 231333°_{5/2}$
6395.00	20	15632.89	$223200\ _{9/2} - 238833°_{7/2}$	6595.93	1	15156.68	$213312\ _{1/2} - 228468°_{3/2}$
6397.98	2	15625.61	$197400\ _{5/2} - 213025°_{5/2}$	6615.73	2	15111.32	
6402.79	15	15613.88	$223174\ _{7/2} - 238788°_{9/2}$	6628.94	1	15081.20	$216376\ _{3/2} - 231457°_{3/2}$
6431.58	15	15543.98		6644.13	20	15046.72	$223787\ _{5/2} - 238833°_{7/2}$
6439.13	10	15525.76	$215807\ _{3/2} - 231333°_{5/2}$	6739.57	30	14833.65	$201732\ _{3/2} - 216565°_{5/2}$
6472.64	1	15445.38	$213514\ _{3/2} - 228960°_{5/2}$	6753.65	20	14802.72	$201215\ _{5/2} - 216017°_{7/2}$
6478.19	1	15432.15	$226857°_{5/2} - 242290\ _{5/2}$	6776.61	1	14752.57	
6501.58	15	15376.63	$197038\ _{11/2} - 212415°_{9/2}$	6793.20	50	14716.54	$201732\ _{3/2} - 216448°_{3/2}$
6508.61	2	15360.02	$197055\ _{7/2} - 212415°_{9/2}$	6826.29	10	14645.20	$224503\ _{3/2} - 239148°_{3/2}$
6512.54	20	15350.75	$201215\ _{3/2} - 216565°_{5/2}$	6831.58	1	14633.86	$240852°_{9/2} - 255486\ _{7/2}$
6528.82	2	15312.47	$216145\ _{5/2} - 231457°_{3/2}$	6851.62	3	14591.06	

[a] Partly second order.
[b] Partly Cu II.

TABLE 2. *Observed terms of* Cu III

Configuration	Observed terms				
$3d^9$	$3d\,^2D$				
$3d^7 4s^2$	$s^2\,^4F\,^2G\,^2H\,^2F$				
	$ns(n \geq 4)$	$np(n \geq 4)$	$nd(n \geq 4)$	$nf(n \geq 4)$	$ng(n \geq 5)$
$3d^8(^3F)nx$	$4s$ to $7s$ ^{4} & ^{2} F	$4p$ & $5p$ ^{4} & ^{2}DFG	$4d$ to $5d$ ^{4} & ^{2}PDFGH	$4f$ ^{4} & ^{2}SPDFGHI	$5g$ ^{4} & ^{2}PDFGHIK
$3d^8(^1D)nx$	$4s'$ to $6s'$ ^{2}D	$4p'$ & $5p'$ ^{2}PDF	$4d'$ to $5d'$ ^{2}SPDFG	$4f'$ ^{2}DFGH	$5g'$ ^{2}GHI
$3d^8(^3P)nx$	$4s''$ to $6s''$ ^{4} & ^{2}P	$4p''$ & $5p''$ ^{4} & ^{2}SPD	$4d''$ to $5d''$ ^{4} & ^{2}PDF	$4f''$ ^{4}DFG ^{2}G	
$3d^8(^1G)nx$	$4s'''$ to $6s'''$ ^{2}G	$4p'''$ & $5p'''$ ^{2}FGH	$4d'''$ to $5d'''$ ^{2}DFGHI	$4f'''$ ^{2}GHIK	$5g'''$ ^{2}L
$3d^8(^1S)nx$	$4s^{IV}$ ^{2}S	$4p^{IV}$ ^{2}P			
$3d^7(^4F)4s4p(^3P)$		z^4DFG ^{2}D			
$3d^7(^4F)4s4p(^1P)$		x^4DFG			
$3d^7(^2G)4s4p(^3P)$		$y^4F_{4\frac{1}{2}}$			
$3d^7(^2P)4s4p(^3P)$		w^4D			
$3d^7(^2H)4s4p(^3P)$		w^4G			
$3d^7(^2D)4s4p(^3P)$		v^4D & w^4F			
$3d^7 4s4p$		1° to 7°			

of a level is reduced in most cases to just two, a very strong one for which both ΔL and ΔJ are in the same direction as Δl, and a second much weaker line for which ΔL and ΔJ are zero. The result is that many levels must be represented by just one combination and consequently there is no real evidence for choosing them.

3. Differences Between Observed and Calculated Levels

Among the low even levels, $4s''\ ^4P_{11/2}$, $^4P_{1/2}$, $^2P_{11/2}$, $^2P_{1/2}$ all differ by over 100 cm^{-1} from the calculated positions, but there can be no doubt of the experimental values. $4s^{IV}\ ^2S$ is 536 cm^{-1} below the calculated value but, again, the evidence is conclusive.

The $s^2\ ^2F_{21/2}$ level mentioned above is 497 cm^{-1} too high, and the $4d'\ ^2F_{21/2}$ is 202 cm^{-1} too low. Although those two levels are 4500 cm^{-1} apart, I suggest that the deviations from theory may be due to their mutual repulsion.

After the $4f$ levels were identified there remained in the same part of the spectrum a considerable number of strong lines which had to be due to transitions between the $4d$ and $4f$ configurations, but there did not appear to be much agreement between them and the theoretical predictions. Accordingly, I tried for levels which might be about 300 cm^{-1} from the predicted values. That led to the definite identification of five $4f'$ levels and two less certain ones. There still remained some of the strongest lines and several of them appeared in pairs. Ignoring the calculations, I tried the strongest pair as the diagonals of the multiplet $4d'''\ ^2I - 4f'''\ ^2K$ and found two levels very close together, as they should be. The next two strongest lines were then assumed to be $4d'''\ ^2H - 4f'''\ ^2I$, and I found two levels 8 cm^{-1} apart. The reality of the levels was confirmed by two additional combinations of $4f'''\ ^2I_{5\,1/2}$. Continuing the analysis by this method, I found $4f'''\ ^2H$, ^2G, and $^2F_{31/2}$ with sufficient combinations to confirm the whole set. The differences between observed and calculated values were very large,[3] ranging from +1366 to +1512 cm^{-1}. Having eliminated from consideration most of the strong lines as due to

[3] These large deviations of the predicted levels have since been corrected by the addition of effective interactions to the matrices for this configuration [8].

$4f'''$, I then found it possible to identify with some certainty ten $4f''$ levels with differences from predicted values from -181 to $+121$. It should be noticed that the differences for the $4f'$ and $4f'''$ levels were of opposite sign. None of the levels combines with any level except those of its own family or with $s^2\ ^2F$, which is very much mixed with the $4d''$ levels.

The $5g$ levels produced a considerable number of diffuse lines in the region of 22,500 to 23,000 cm^{-1}, which are very difficult to measure. I have found it possible, however, to identify 31 of the 41 levels based on ^3F with some certainty. From the remaining lines it was possible to make a definite identification of $5g'\ ^2G$ and tentative identifications of $5g'\ ^2I$ and $5g'\ ^2H$. A possible $5g'''\ ^2L$ is also given in table 3.

TABLE 3. *Even levels of* Cu III

Configuration	Name	Level (cm^{-1})
$3d^9$	$3d\ ^2D_{2\frac{1}{2}}$	0.00
	$3d\ ^2D_{1\frac{1}{2}}$	2071.69
$3d^8(^3F_4)4s$	$4s\ ^4F_{4\frac{1}{2}}$	60805.22
	$4s\ ^4F_{3\frac{1}{2}}$	62065.09
$3d^8(^3F_3)4s$	$4s\ ^4F_{2\frac{1}{2}}$	63143.77
$3d^8(^3F_2)4s$	$4s\ ^4F_{1\frac{1}{2}}$	63886.51
$3d^8(^3F_3)4s$	$4s\ ^2F_{3\frac{1}{2}}$	67016.71
$3d^8(^3F_2)4s$	$4s\ ^2F_{2\frac{1}{2}}$	68963.78
$3d^8(^1D)4s$	$4s'\ ^2D_{2\frac{1}{2}}$	77968.25
	$4s'\ ^2D_{1\frac{1}{2}}$	78780.00
$3d^8(^3P)4s$	$4s''\ ^4P_{1\frac{1}{2}}$	80305.74
	$4s''\ ^4P_{\frac{1}{2}}$	80423.54
	$4s''\ ^4P_{2\frac{1}{2}}$	80552.14
	$4s''\ ^2P_{1\frac{1}{2}}$	85447.29
	$4s''\ ^2P_{\frac{1}{2}}$	86133.66
$3d^8(^1G)4s$	$4s'''\ ^2G_{4\frac{1}{2}}$	89018.30
	$4s'''\ ^2G_{3\frac{1}{2}}$	89046.71
$3d^8(^1S)4s$	$4s^{iv}\ ^2S_{\frac{1}{2}}$	122860.82
$3d^74s^2$	$4s^2\ ^4F_{4\frac{1}{2}}$	166159.36
	$4s^2\ ^4F_{3\frac{1}{2}}$	167739.09
	$4s^2\ ^4F_{2\frac{1}{2}}$	168856.96
	$4s^2\ ^4F_{1\frac{1}{2}}$	169608.26
	$4s^2\ ^2G_{4\frac{1}{2}}$	188097.72
	$4s^2\ ^2G_{3\frac{1}{2}}$	189602.62
$3d^8(^3F_4)5s$	$5s\ ^4F_{4\frac{1}{2}}$	193370.76
$3d^8(^3F_4)4d$	$4d\ ^4D_{3\frac{1}{2}}$	193520.75
	$4d\ ^4P_{2\frac{1}{2}}$	193885.30
	$4d\ ^4H_{5\frac{1}{2}}$	194033.26
$3d^8(^3F_4)5s$	$5s\ ^4F_{3\frac{1}{2}}$	194117.14
$3d^8(^3F_4)4d$	$4d\ ^4H_{6\frac{1}{2}}$	194331.79
	$4d\ ^4P_{1\frac{1}{2}}$	194683.69
	$4d\ ^4G_{5\frac{1}{2}}$	194818.37
	$4d\ ^4F_{4\frac{1}{2}}$	195061.88
	$4d\ ^4D_{2\frac{1}{2}}$	195340.40
	$4d\ ^4F_{3\frac{1}{2}}$	195343.79
	$4d\ ^4G_{4\frac{1}{2}}$	195518.43
$3d^8(^3F_3)5s$	$5s\ ^4F_{2\frac{1}{2}}$	195555.12
$3d^8(^3F_3)4d$	$4d\ ^4P_{\frac{1}{2}}$	195722.78
$3d^74s^2$	$4s^2\ ^2H_{5\frac{1}{2}}$	195757.94
$3d^8(^3F_3)5s$	$5s\ ^2F_{3\frac{1}{2}}$	195788.65
$3d^8(^3F_3)4d$	$4d\ ^4H_{4\frac{1}{2}}$	196028.66
	$4d\ ^2P_{1\frac{1}{2}}$	196100.20
$3d^8(^3F_2)5s$	$5s\ ^4F_{1\frac{1}{2}}$	196442.14
$3d^8(^3F_3)4d$	$4d\ ^4F_{2\frac{1}{2}}$	196730.75
	$4d\ ^4G_{3\frac{1}{2}}$	196742.34
$3d^74s^2$	$4s^2\ ^2H_{4\frac{1}{2}}$	196795.53
$3d^8(^3F_3)4d$	$4d\ ^4D_{1\frac{1}{2}}$	196806.22
	$4d\ ^2H_{5\frac{1}{2}}$	197038.62
	$4d\ ^2F_{3\frac{1}{2}}$	197055.18
$3d^8(^3F_2)4d$	$4d\ ^4D_{\frac{1}{2}}$	197199.63
$3d^8(^3F_3)4d$	$4d\ ^2G_{4\frac{1}{2}}$	197375.85

TABLE 3. *Even levels of* Cu III—Continued

Configuration	Name	Level (cm^{-1})
$3d^8(^3F_2)5s$	$5s\ ^2F_{2\frac{1}{2}}$	197400.19
$3d^8(^3F_2)4d$	$4d\ ^4H_{3\frac{1}{2}}$	197593.69
	$4d\ ^4G_{2\frac{1}{2}}$	197900.51
	$4d\ ^4F_{1\frac{1}{2}}$	197985.57
	$4d\ ^2P_{\frac{1}{2}}$	198033.60
	$4d\ ^2F_{2\frac{1}{2}}$	198061.23
	$4d\ ^2H_{4\frac{1}{2}}$	198687.18
	$4d\ ^2G_{3\frac{1}{2}}$	198930.42
$3d^8(^3F_3)4d$	$4d\ ^2D_{2\frac{1}{2}}$	201215.00
$3d^8(^3F_2)4d$	$4d\ ^2D_{1\frac{1}{2}}$	201732.15
$3d^8(^1D)5s$	$5s'\ ^2D_{2\frac{1}{2}}$	209875.15
	$5s'\ ^2D_{1\frac{1}{2}}$	210033.19
$3d^8(^1D)4d$	$4d'\ ^2F_{2\frac{1}{2}}$	210159.14
	$4d'\ ^2F_{3\frac{1}{2}}$	210239.88
	$4d'\ ^2D_{1\frac{1}{2}}$	211123.91
	$4d'\ ^2G_{3\frac{1}{2}}$	211271.32
	$4d'\ ^2P_{1\frac{1}{2}}$	211286.05
	$4d'\ ^2G_{4\frac{1}{2}}$	211313.62
	$4d'\ ^2P_{1\frac{1}{2}}$	211652.05
	$4d'\ ^2D_{2\frac{1}{2}}$	211679.61
	$4d'\ ^2S_{\frac{1}{2}}$	212208.63
$3d^8(^3P)4d$	$4d''\ ^4D_{3\frac{1}{2}}$	212752.39
$3d^8(^3P)5s$	$5s''\ ^4P_{2\frac{1}{2}}$	212951.03
	$5s''\ ^4P_{1\frac{1}{2}}$	213127.07
$3d^8(^3P)4d$	$4d''\ ^4D_{2\frac{1}{2}}$	213133.65
	$4d''\ ^4D_{\frac{1}{2}}$	213141.65
	$4d''\ ^4D_{1\frac{1}{2}}$	213312.19
$3d^8(^3P)5s$	$5s''\ ^4P_{\frac{1}{2}}$	213418.17
$3d^74s^2$	$4s^2\ ^2F_{2\frac{1}{2}}$	213514.78
	$4s^2\ ^2F_{3\frac{1}{2}}$	213815.69
$3d^8(^3P)5s$	$5s''\ ^2P_{1\frac{1}{2}}$	214264.50
	$5s''\ ^2P_{\frac{1}{2}}$	214730.18
$3d^8(^3P)4d$	$4d''\ ^4F_{4\frac{1}{2}}$	214747.99
	$4d''\ ^4F_{3\frac{1}{2}}$	214844.87
	$4d''\ ^4F_{2\frac{1}{2}}$	214989.62
	$4d''\ ^2D_{2\frac{1}{2}}$	215100.44
	$4d''\ ^4F_{1\frac{1}{2}}$	215197.18
	$4d''\ ^4P_{\frac{1}{2}}$	215761.54
	$4d''\ ^4P_{1\frac{1}{2}}$	215807.35
	$4d''\ ^2F_{3\frac{1}{2}}$	215976.94
	$4d''\ ^4P_{2\frac{1}{2}}$	216145.05
	$4d''\ ^2D_{1\frac{1}{2}}$	216235.32
	$4d''\ ^2F_{2\frac{1}{2}}$	216376.27
	$4d''\ ^2P_{\frac{1}{2}}$	216833.51
$3d^8(^1G)4d$	$4d'''\ ^2I_{5\frac{1}{2}}$	220311.20
	$4d'''\ ^2I_{6\frac{1}{2}}$	220413.54
$3d^8(^1G)5s$	$5s'''\ ^2G_{4\frac{1}{2}}$	220563.89
	$5s'''\ ^2G_{3\frac{1}{2}}$	220569.48
$3d^8(^1G)4d$	$4d'''\ ^2F_{3\frac{1}{2}}$	221861.15
	$4d'''\ ^2F_{2\frac{1}{2}}$	221878.97
	$4d'''\ ^2H_{4\frac{1}{2}}$	223089.88
	$4d'''\ ^2G_{3\frac{1}{2}}$	223174.34
	$4d'''\ ^2H_{5\frac{1}{2}}$	223175.15
	$4d'''\ ^2G_{4\frac{1}{2}}$	223200.87
	$4d'''\ ^2D_{2\frac{1}{2}}$	223787.07
	$4d'''\ ^2D_{1\frac{1}{2}}$	224503.61
$3d^8(^3F_4)6s$	$6s\ ^4F_{4\frac{1}{2}}$	238280.09
	$6s\ ^4F_{3\frac{1}{2}}$	238638.49
$3d^8(^3F_4)5d$	$5d\ ^4D_{3\frac{1}{2}}$	238730.93
	$5d\ ^4P_{2\frac{1}{2}}$	238818.98
	$5d\ ^4H_{6\frac{1}{2}}$	238994.08
	$5d\ ^4H_{5\frac{1}{2}}$	239112.04
	$5d\ ^4G_{5\frac{1}{2}}$	239240.10
	$5d\ ^4F_{4\frac{1}{2}}$	239290.03
	$5d\ ^4P_{1\frac{1}{2}}$	239326.97
	$5d\ ^4F_{3\frac{1}{2}}$	239440.71
	$5d\ ^4G_{4\frac{1}{2}}$	239568.88
	$5d\ ^4D_{2\frac{1}{2}}$	240062.88
$3d^8(^3F_3)6s$	$6s\ ^2F_{3\frac{1}{2}}$	240303.20
	$6s\ ^4F_{2\frac{1}{2}}$	240325.65
$3d^8(^3F_3)5d$	$5d\ ^4P_{\frac{1}{2}}$	240764.06

TABLE 3. *Even levels of* Cu III – Continued

Configuration	Name	Level (cm^{-1})
	$5d\ ^2P_{1/2}$	240794.56
	$5d\ ^2H_{5/2}$	240960.52
	$5d\ ^4H_{4/2}$	240972.55
$3d^8(^3F_3)5d$	$5d\ ^4F_{2/2}$	240994.59
	$5d\ ^2F_{3/2}$	241074.10
	$5d\ ^2G_{4/2}$	241215.61
	$5d\ ^4G_{3/2}$	241249.83
$3d^8(^3F_2)6s$	$6s\ ^4F_{1/2}$	241328.02
$3d^8(^3F_3)5d$	$5d\ ^4D_{1/2}$	241391.60
$3d^8(^3F_2)6s$	$6s\ ^2F_{2/2}$	241693.54
$3d^8(^3F_2)5d$	$5d\ ^4D_{1/2}$	241899.60
	$5d\ ^2F_{2/2}$	242006.56
	$5d\ ^4H_{3/2}$	242088.67
	$5d\ ^4F_{1/2}$	242219.08
	$5d\ ^2P_{1/2}$	242247.32
	$5d\ ^4G_{2/2}$	242290.02
	$5d\ ^2H_{4/2}$	242297.51
	$5d\ ^2G_{3/2}$	242610.05
$3s^8(^3F_3)5d$	$5d\ ^2D_{2/2}$	243780.33
$3d^8(^3F_2)5d$	$5d\ ^2D_{1/2}$	244618.53
$3d^8(^1D)6s$	$6s'\ ^2D_{2/2}$	254620.28
	$6s'\ ^2D_{1/2}$	254694.27
$3d^8(^1D)5d$	$5d'\ ^2F_{3/2}$	255173.30
	$5d'\ ^2G_{4/2}$	255458.91 ?
	$5d'\ ^2G_{3/2}$	255486.66 ?
	$5d'\ ^2P_{1/2}$	255750.15
	$5d'\ ^2D_{2/2}$	256093.09 ?
$3d^8(^3F_4)5g$	$5g\ ^4P_{2/2}$	257488.98
	$5g\ ^4P_{1/2}$	257495.26
	$5g\ ^4K_{7/2}$	257504.55
	$5g\ ^4K_{8/2}$	257504.70
	$5g\ ^4D_{3/2}$	257514.75
	$5g\ ^4G_{5/2}$	257530.89
	$5g\ ^4I_{6/2}$	257540.31
	$5g\ ^4I_{7/2}$	257540.49
	$5g\ ^4H_{5/2}$	257566.45
	$5g\ ^4H_{6/2}$	257565.23
	$5g\ ^4F_{4/2}$	257574.15 ?
	$5g\ ^4P_{1/2}$	257602.70
	$5g\ ^4G_{4/2}$	257625.54
	$5g\ ^4F_{3/2}$	257668.09 ?
	$5g\ ^4D_{2/2}$	257671.85
$3d^8(^3P)6s$	$6s''\ ^4P_{2/2}$	257885.87
$3d^8(^3P)5d$	$5d''\ ^4D_{3/2}$	258199.34 ?
	$5d''\ ^4F_{4/2}$	258855.31 ?
	$5d''\ ^4F_{3/2}$	259018.09 ?
$3d^8(^3F_4)7s$	$7s\ ^4F_{4/2}$	259147.46 ?
$3d^8(^3F_3)5g$	$5g\ ^4K_{6/2}$	259371.79
	$5g\ ^2K_{7/2}$	259372.09
	$5g\ ^4H_{4/2}$?	259402.75 ?
	$5g\ ^2G_{4/2}$?	259402.75
	$5g\ ^4I_{5/2}$	259404.25
	$5g\ ^2I_{6/2}$	259404.43
	$5g\ ^2H_{5/2}$	259417.64
	$5g\ ^2P_{1/2}$	259432.58
	$5g\ ^2D_{2/2}$	259470.16
$3d^8(^3F_2)5g$	$5g\ ^4K_{5/2}$	260590.96
	$5g\ ^2K_{6/2}$	260591.04
	$5g\ ^4H_{3/2}$	260632.62 ?
	$5g\ ^2I_{5/2}$	260646.03 ?
	$5g\ ^4I_{4/2}$	260676.45 ?
$3d^8(^1G)6s$	$6s'''\ ^2G_{4/2}$	265292.86 ?
$3d^8(^1G)5d$	$5d'''\ ^2I_{5/2}$	265544.10
	$5d'''\ ^2I_{6/2}$	265589.57
	$5d'''\ ^2F_{3/2}$	266079.82
	$5d'''\ ^2F_{2/2}$	266091.84
	$5d'''\ ^2H_{4/2}$	266597.63
	$5d'''\ ^2H_{5/2}$	266637.30
	$5d'''\ ^2G_{3/2}$	266643.08
	$5d'''\ ^2G_{4/2}$	266653.32
	$5d'''\ ^2D_{2/2}$	267031.05

TABLE 3. *Even levels of* Cu III – Continued

Configuration	Name	Level (cm^{-1})
	$5d'''\ ^2D_{1/2}$	267310.38
$3d^8(^1D)5g$	$5g'\ ^2H_{5/2}$	273732.91 ?
	$5g'\ ^2H_{4/2}$	273738.68 ?
	$5g'\ ^2I_{5/2}$	273799.53 ?
	$5g'\ ^2G_{3/2}$	273800.58
	$5g'\ ^2I_{6/2}$	273802.30 ?
	$5g'\ ^2G_{4/2}$	273807.19
$3d^8(^1G)5g$	$5g'''\ ^2L_{8/2}$	284095.50
	$5g'''\ ^2L_{7/2}$	284098.12
Cu IV $3d^8\ ^3F_4$		297140

TABLE 4. *Odd levels of* Cu III

Configuration	Name	Level (cm^{-1})
$3d^8(^3F)4p$	$4p\ ^4D_{3/2}$	118864.85
	$4p\ ^4D_{2/2}$	120577.85
	$4p\ ^4G_{4/2}$	121337.72
	$4p\ ^4G_{5/2}$	121699.08
	$4p\ ^4D_{1/2}$	121864.48
	$4p\ ^4G_{3/2}$	122504.09
	$4p\ ^4D_{1/2}$	122637.26
	$4p\ ^4G_{2/2}$	123440.69
	$4p\ ^4F_{4/2}$	123550.38
	$4p\ ^2G_{4/2}$	124442.77
	$4p\ ^4F_{3/2}$	124557.85
	$4p\ ^4F_{2/2}$	125382.09
	$4p\ ^4F_{1/2}$	125744.81
	$4p\ ^2G_{3/2}$	126094.14
	$4p\ ^2F_{3/2}$	126829.76
	$4p\ ^2D_{2/2}$	126892.24
	$4p\ ^2D_{1/2}$	128435.61
	$4p\ ^2F_{2/2}$	128679.85
$3d^8(^3P)4p$	$4p''\ ^4P_{1/2}$	136483.63
	$4p''\ ^4P_{2/2}$	136607.85
	$4p''\ ^4P_{1/2}$	137041.60
$3d^8(^1D)4p$	$4p'\ ^2F_{2/2}$	138084.98
	$4p'\ ^2F_{3/2}$	138982.86
	$4p'\ ^2D_{1/2}$	138989.01
	$4p'\ ^2P_{1/2}$	139261.52
	$4p'\ ^2D_{2/2}$	139757.46
	$4p'\ ^2P_{1/2}$	140201.72
$3d^8(^3P)4p$	$4p''\ ^4D_{2/2}$	142427.10
	$4p''\ ^4D_{1/2}$	142513.20
	$4p''\ ^4D_{1/2}$	142550.75
	$4p''\ ^4D_{3/2}$	142820.01
	$4p''\ ^2D_{2/2}$	144195.35
	$4p''\ ^2D_{1/2}$	144876.29
	$4p''\ ^2P_{1/2}$	145353.84
$3d^8(^1G)4p$	$4p'''\ ^2H_{4/2}$	146534.51
$3d^8(^3P)4p$	$4p''\ ^2P_{1/2}$	146675.34
$3d^8(^1G)4p$	$4p'''\ ^2H_{5/2}$	147647.87
$3d^8(^3P)4p$	$4p''\ ^2S_{1/2}$	147653.36
$3d^8(^1G)4p$	$4p''\ ^4S_{1/2}$	147806.69
$3d^8(^3P)4p$	$4p'''\ ^2F_{3/2}$	147817.32
$3d^8(^1G)4p$	$4p'''\ ^2F_{2/2}$	148663.85
	$4p'''\ ^2G_{3/2}$	153609.87
	$4p'''\ ^2G_{4/2}$	153808.22
$3d^8(^1S)4p$	$4p^{IV}\ ^2P_{1/2}$	182900.11
	$4p^{IV}\ ^2P_{1/2}$	184197.12
$3d^8(^3F_4)5p$	$5p\ ^4D_{3/2}$	211821.00
	$5p\ ^4G_{4/2}$	212415.20
	$5p\ ^4G_{5/2}$	212525.35
	$5p\ ^4F_{4/2}$	212995.16
	$5p\ ^4D_{2/2}$	213025.70

TABLE 4. *Odd levels of* Cu III — Continued

Configuration	Name	Level (cm^{-1})
	$5p\ {}^4F_{3\frac{1}{2}}$	213311.78
$3d^8(^3F_3)5p$	$5p\ {}^4G_{3\frac{1}{2}}$	214328.03
	$5p\ {}^4D_{1\frac{1}{2}}$	214357.95
	$5p\ {}^2G_{4\frac{1}{2}}$	214588.27
	$5p\ {}^2D_{2\frac{1}{2}}$	214702.78
	$5p\ {}^4F_{2\frac{1}{2}}$	214766.34
	$5p\ {}^2F_{3\frac{1}{2}}$	215000.50
$3d^8(^3F_2)5p$	$5p\ {}^4D_{1\frac{1}{2}}$	215160.74
	$5p\ {}^4G_{2\frac{1}{2}}$	215417.25
	$5p\ {}^4F_{1\frac{1}{2}}$	215782.96
	$5p\ {}^2G_{3\frac{1}{2}}$	216017.68
	$5p\ {}^2D_{1\frac{1}{2}}$	216448.63
	$5p\ {}^2F_{2\frac{1}{2}}$	216565.74
$3d^7(^4F)sp(^3P)$	$z\ {}^4F_{4\frac{1}{2}}$	223134.65
	$z\ {}^4G_{5\frac{1}{2}}$	223229.90
	$z\ {}^4F_{3\frac{1}{2}}$	223570.61
	$z\ {}^4G_{4\frac{1}{2}}$	224048.02
	$z\ {}^4F_{2\frac{1}{2}}$	224450.45
	$z\ {}^4F_{1\frac{1}{2}}$	225235.39
	$z\ {}^4D_{3\frac{1}{2}}$	225923.90
	$z\ {}^4D_{2\frac{1}{2}}$	226857.54
	$z\ {}^4D_{1\frac{1}{2}}$	227494.85
	$z\ {}^4D_{\frac{1}{2}}$	227964.02 ?
$3d^8(^1D)5p$	$5p'\ {}^2D_{2\frac{1}{2}}$	228423.50
	$5p'\ {}^2D_{1\frac{1}{2}}$	228468.86
	$5p'\ {}^2F_{2\frac{1}{2}}$	228960.05
	$5p'\ {}^2P_{\frac{1}{2}}$	229054.02
	$5p'\ {}^2F_{3\frac{1}{2}}$	229098.47
	$5p'\ {}^2P_{1\frac{1}{2}}$	229505.30
$3d^8(^3P)5p$	$5p''\ {}^4P_{\frac{1}{2}}$	231298.41 ?
	$5p''\ {}^4P_{2\frac{1}{2}}$	231333.00
	$5p''\ {}^4P_{1\frac{1}{2}}$	231457.50
	$5p''\ {}^4D_{3\frac{1}{2}}$	232435.96
	$5p''\ {}^4D_{2\frac{1}{2}}$	232458.10
	$5p''\ {}^4D_{1\frac{1}{2}}$	232478.23 ?
	$5p''\ {}^2P_{1\frac{1}{2}}$	232814.29
$3d^7(^4F)sp(^3P)$	$z\ {}^2D_{2\frac{1}{2}}$	232989.62 ?
$3d^8(^3P)5p$	$5p''\ {}^2D_{2\frac{1}{2}}$	233285.96
	$5p''\ {}^2D_{1\frac{1}{2}}$	233653.51
	$5p''\ {}^4S_{1\frac{1}{2}}$	234036.16
$3d^8(^3F_4)4f$	$4f\ {}^4S_{1\frac{1}{2}}$	234427.01
	$4f\ {}^4P_{2\frac{1}{2}}$	234490.73
	$4f\ {}^2S_{\frac{1}{2}}$	234530.60
	$4f\ {}^4I_{6\frac{1}{2}}$	234532.91
	$4f\ {}^4I_{7\frac{1}{2}}$	234537.43
	$4f\ {}^4D_{3\frac{1}{2}}$	234562.13
$3d^7(^4F)sp(^3P)$	$z\ {}^2D_{1\frac{1}{2}}$	234650.41 ?
$3d^8(^3F_4)4f$	$4f\ {}^4F_{4\frac{1}{2}}$	234654.68
	$4f\ {}^4P_{1\frac{1}{2}}$	234660.53
	$4f\ {}^4H_{6\frac{1}{2}}$	234670.98
	$4f\ {}^4H_{5\frac{1}{2}}$	234681.35
	$4f\ {}^4G_{5\frac{1}{2}}$	234716.80
	$4f\ {}^4G_{4\frac{1}{2}}$	234774.74
	$4f\ {}^4D_{2\frac{1}{2}}$	234775.00
	$4f\ {}^4F_{3\frac{1}{2}}$	234812.88
$3d^8(^3F_3)4f$	$4f\ {}^4P_{\frac{1}{2}}$	236323.71
	$4f\ {}^4D_{\frac{1}{2}}$	236370.88
	$4f\ {}^2P_{1\frac{1}{2}}$	236395.02
	$4f\ {}^2I_{6\frac{1}{2}}$	236417.68
	$4f\ {}^4I_{5\frac{1}{2}}$	236418.68
	$4f\ {}^4F_{2\frac{1}{2}}$	236471.28
	$4f\ {}^4D_{1\frac{1}{2}}$	236484.91
	$4f\ {}^4F_{3\frac{1}{2}}$	236511.51
	$4f\ {}^2H_{5\frac{1}{2}}$	236531.91
	$4f\ {}^2G_{4\frac{1}{2}}$	236537.18
	$4f\ {}^4H_{4\frac{1}{2}}$	236550.40
	$4f\ {}^2D_{2\frac{1}{2}}$	236590.41
	$4f\ {}^4G_{3\frac{1}{2}}$	236611.48
$3d^8(^3F_2)4f$	$4f\ {}^4F_{1\frac{1}{2}}$	237538.57
	$4f\ {}^2P_{3\frac{1}{2}}$	237591.35
	$4f\ {}^2I_{5\frac{1}{2}}$	237641.05

TABLE 4. *Odd levels of* Cu III — Continued

Configuration	Name	Level (cm^{-1})
	$4f\ {}^4I_{4\frac{1}{2}}$	237644.52
	$4f\ {}^2F_{2\frac{1}{2}}$	237674.38
	$4f\ {}^2D_{1\frac{1}{2}}$	237734.00
	$4f\ {}^2G_{3\frac{1}{2}}$	237751.21
	$4f\ {}^2H_{4\frac{1}{2}}$	237778.99
	$4f\ {}^4H_{3\frac{1}{2}}$	237814.57
	$4f\ {}^4G_{2\frac{1}{2}}$	237830.63
$3d^8(^1G)5p$	$5p'''\ {}^2H_{4\frac{1}{2}}$	238788.16
	$5p'''\ {}^2F_{3\frac{1}{2}}$	238833.78
	$5p'''\ {}^2H_{5\frac{1}{2}}$	239142.42
	$5p'''\ {}^2F_{2\frac{1}{2}}$	239148.82
$3d^7(^2G)sp(^3P)$	$y\ {}^4F_{4\frac{1}{2}}$	239606.85
$3d^8(^1G)5p$	$5p'''\ {}^2G_{3\frac{1}{2}}$	240786.48
	$5p'''\ {}^2G_{4\frac{1}{2}}$	240852.75
$3d^7(^2P)sp(^3P)$	$w\ {}^4D_{3\frac{1}{2}}$	243234.10
	$w\ {}^4D_{2\frac{1}{2}}$	244602.61
$3d^7(^2H)sp(^3P)$	$w\ {}^4G_{5\frac{1}{2}}$	245139.94
$3d^7(^2D)sp(^3P)$	$v\ {}^4D_{3\frac{1}{2}}$	245671.35
$3d^7sp$	$1°_{4\frac{1}{2}}$	246202.65
$3d^7(^2H)sp(^3P)$	$w\ {}^4G_{4\frac{1}{2}}$	246439.20
$3d^7(^2D)sp(^3P)$	$w\ {}^4F_{4\frac{1}{2}}$	246510.54
	$w\ {}^4F_{3\frac{1}{2}}$	247475.26
$3d^7(^4F)sp(^1P)$	$x\ {}^4G_{5\frac{1}{2}}$	247578.66
	$x\ {}^4F_{4\frac{1}{2}}$	247902.05
$3d^7sp$	$2°_{4\frac{1}{2}}$	247924.26
	$3°_{3\frac{1}{2}}$	248013.84
$3d^7(^2D)sp(^3P)$	$w\ {}^4F_{2\frac{1}{2}}$	248281.96
$3d^7sp$	$4°_{4\frac{1}{2}}$	248360.45
$3d^7(^2D)sp(^3P)$	$w\ {}^4F_{1\frac{1}{2}}$	248896.92
$3d^7(^4F)sp(^1P)$	$x\ {}^4G_{4\frac{1}{2}}$	249077.07
$3d^7sp$	$5°_{2\frac{1}{2}}$	249353.93
	$6°_{2\frac{1}{2}}$	249421.55
$3d^7(^4F)sp(^1P)$	$x\ {}^4G_{3\frac{1}{2}}$	250168.06
	$x\ {}^4D_{3\frac{1}{2}}$	250419.48
	$x\ {}^4F_{3\frac{1}{2}}$	250636.95
$3d^8(^1D)4f$	$4f'\ {}^2F_{2\frac{1}{2}}$	250731.98
$3d^8(^1D)4f$	$4f'\ {}^2G_{3\frac{1}{2}}$	250733.55
	$4f'\ {}^2G_{4\frac{1}{2}}$	250734.45
	$4f'\ {}^2F_{3\frac{1}{2}}$	250817.68
	$4f'\ {}^2H_{2\frac{1}{2}}$	250955.22 ?
	$4f'\ {}^2H_{4\frac{1}{2}}$	250999.71
	$4f'\ {}^2H_{5\frac{1}{2}}$	251010.62
$3d^7(^4F)sp(^1P)$	$x\ {}^4G_{2\frac{1}{2}}$	251052.76 ?
	$x\ {}^4D_{2\frac{1}{2}}$	251932.36
	$x\ {}^4F_{2\frac{1}{2}}$	252437.63
	$x\ {}^4D_{1\frac{1}{2}}$	253102.60
	$x\ {}^4D_{\frac{1}{2}}$	253713.29 ?
$3d^8(^3P)4f$	$4f''\ {}^4F_{4\frac{1}{2}}$	254030.84
	$4f''\ {}^4F_{2\frac{1}{2}}$	254125.74
	$4f''\ {}^2F_{3\frac{1}{2}}$	254132.14
$3d^7(^4F)sp(^1P)$	$x\ {}^4F_{1\frac{1}{2}}$	254147.19 ?
$3d^8(^3P)4f$	$4f''\ {}^2G_{4\frac{1}{2}}$	254448.81
	$4f''\ {}^4G_{5\frac{1}{2}}$	254467.96
	$4f''\ {}^4D_{1\frac{1}{2}}$	254673.30 ?
	$4f''\ {}^4G_{3\frac{1}{2}}$	254772.26
	$4f''\ {}^4G_{4\frac{1}{2}}$	254784.41
	$4f''\ {}^4D_{2\frac{1}{2}}$	254794.45
	$4f''\ {}^4D_{3\frac{1}{2}}$	254926.68
$ed^8(^1G)4f$	$4f'''\ {}^2K_{7\frac{1}{2}}$	261167.97
	$4f'''\ {}^2K_{6\frac{1}{2}}$	261169.55
	$4f'''\ {}^2F_{3\frac{1}{2}}$	261563.41
	$4f'''\ {}^2G_{4\frac{1}{2}}$	261757.14
	$4f'''\ {}^2G_{3\frac{1}{2}}$	261762.79
	$4f'''\ {}^2I_{6\frac{1}{2}}$	261812.11
	$4f'''\ {}^2I_{5\frac{1}{2}}$	261820.32
	$4f'''\ {}^2H_{4\frac{1}{2}}$	261995.84
	$4f'''\ {}^2H_{5\frac{1}{2}}$	261998.41
Cu IV $3d^8\ {}^3F_4$		297140

The numerical differences between observed and calculated levels are quite definite. Differences between the names assigned by the two methods are fairly frequent, and are of course based on less definite evidence. In particular, in the $4d$ groups of levels, there are 17 cases of differing names. This is partly due to the presence of the $s^2\,{}^2H$ term and the thorough way in which it is embedded amongst the $4d$ levels. In no case, however, in any of the various structures is there as extreme a disagreement as is described in [2, Addenda] for the case of $4p\,{}^4G_{4\frac{1}{2}}$, $4p\,{}^4F_{4\frac{1}{2}}$, $4p\,{}^2G_{4\frac{1}{2}}$ in Ni II.

After much of the analysis was done, there were many unidentified lines in the short wavelength end of the spectrum. On examination, I found that most of them could be paired off by differences between $4s\,{}^4F$ and $4s^2\,{}^4F$. Since they had to be due to levels of $3d^7 4s4p$, I plotted them on a graph with the levels of Co I and Ni II and was able to identify the origin of the majority of them. They appear in the term table with the same names as the corresponding levels in Ni II [2]. There are six numbered levels which could not be included amongst those identified.

4. Ionization Potential

The most important and reliable series from which to calculate a limit is the series $ns\,{}^4F_{4\frac{1}{2}}$ in which there are three members quite accurately determined and a fourth which is undependable. A Ritz calculation of $4s$, $5s$, $6s\,{}^4F_{4\frac{1}{2}}$ yields a limit 296980 cm^{-1}, the formula being $n^* = n + \mu - \alpha T'$ where $T' = \frac{T}{9}$, $\mu = 0.12070$, and $\alpha = 2.886 \times 10^{-6}$. When the series $ns'\,{}^2D_{2\frac{1}{2}}$, $ns''\,{}^4P_{2\frac{1}{2}}$ and $ns'''\,{}^2G_{4\frac{1}{2}}$ each of three terms are fitted to Ritz formulae without reference to the analysis of Cu IV [7] they yield the following results:

Series	Limit	Limit above $^3F_4$	Limit level in Cu IV [6]	Diff.
$ns\,{}^4F_{4\frac{1}{2}}$	296980	00.	00	00
$ns'\,{}^2D_{2\frac{1}{2}}$	313198	16213.	16249	+36
$ns''\,{}^4P_{2\frac{1}{2}}$	316622	19642.	19696	+54
$ns'''\,{}^2G_{4\frac{1}{2}}$	323881 ?	26901	27074	+173

The values of the limits of the ^2D and ^4P series cannot be much in error, but there is some doubt about the ^2G because the $6s'''\,{}^2G$ term is not well established. It is, however, close to the calculated value.

The comparison of the four series listed above is legitimate because they are all calculated from $4s$, $5s$, and $6s$ levels. It is known of course that, if higher series levels are found, it is possible to derive a more probable value of the true limit. In Ni II, where the series is known up to $9s$, the limit from (4, 5, $6s$) is 146462 cm^{-1}, from (5, 6, $7s$) it is 146521 cm^{-1}, and from (6, 7, 8, $9s$) it is 146532 cm^{-1}. The Ni II limit obtained from the $ng\,{}^4K_{8\frac{1}{2}}$ series, which should be close to the true limit, is 146541 cm^{-1}. If those four values are plotted, they appear to form a curve converging towards the last one at very large values of n. If we accept the limit of 146541 cm^{-1} as being very near the true value and assume that the same relative increase can be applied to Cu III, we can calculate as a probable true ionization potential the value 296980 $cm^{-1} \times 1.00054 = 297140$ cm^{-1}.

5. Analysis of Cu IV

I regret very much that it is incumbent upon me to criticize the paper on Cu IV published in 1970 by J. F. Schröder and Th. A. M. Van Kleef [7]. My criticism is known to Dr. Van Kleef, with whom I have had a considerable correspondence on the subject.

The sources used to excite the spectra in that paper and in this were very similar and the observed spectra were obviously also very similar. Apparently the Cu IV measurement of the lines used fewer good standards than I did for the Cu III spectra, in which I found many Cu II, Si II, C I and Cl I lines given to 10^{-4} Å. The resulting wavelengths differ so much that it would, in many cases, be difficult to identify the same line in the two spectra if it were not for the fact that all the lines of any intensity appear in both spectra. A wavelength difference may be as high as 0.03 Å, but the identity cannot be questioned. It is very odd also that there are about 140 weak lines which I do not observe at all, in spite of immense over-exposure of the strong lines.

My criticism of the Cu IV paper is based on the following facts.

(1) There are nine lines of Cu II included in the analysis and a tenth, the strongest line of Cu II in the Schumann region, 1358.773 Å, which appears as two strong lines due to reversal. The lines are as follows.

Cu II lines λ [7]	λ [3]
2161.995	0.999
2130.763	.758
2085.983	.938 and 973 (AGS)
1929.757	.752
1522.587	.577
1517.918	.930
1472.421	.395
1358.770	.773
1358.732	
1044.748	.744
1039.589	.582

The two lines at 2085 Å are both Cu II, observed in the direct current hollow cathode tube. The two lines at 1358 Å are the two sides of the most heavily reversed line in the Cu II spectrum, $3d^{10}\,{}^1S_0 - 3d^9 4p\,{}^1P_1$. The line at 1472 Å is the companion line $3d^{10}\,{}^1S_0 - 3d^9 4p^3P_1$.

(2) There are five impurity lines.

λ [7]		
1602.960	0.972 C I	[4]
1467.423	.402 C I	[4]
1280.353	.333 C I	[4]
1261.132	.122 C I	[4]
580.970	.967 O II	[9]

(3) Nine second order lines are included.

λ [7]	λ (AGS) Origin	
1576.895	788.460 × 2 = 1576.920	Cu III
1404.247	702.118 × 2 = 1404.236	Cu III
1400.527	700.261 × 2 = 1400.522	Cu III
1373.812	686.902 × 2 = 1373.804	Cu III
1301.999	651.000 × 2 = 1302.000	Cu III
1216.910	608.453 × 2 = 1216.906	Cu III
1165.308	582.657 × 2 = 1165.314	Cu III
1098.151	549.075 × 2 = 1098.150	Cu III
1051.588	525.795 × 2 = 1051.590	O III [9]

(4) Other questionable lines

1654.655	1654.559 Cu III	
1549.288	1549.215 Cu III and 0.306	Cu III?
1348.880	1348.831 Cu III and 0.919	Cu IV
1312.948	Obs-Calc is 13.4 not 0.4 cm^{-1}	
1245.691	1245.643 ? and 0.724 both Cu III	
1240.160	1240.126 and 0.216 both Cu III	

(5) Cu III lines used as Cu IV

There are 69 lines in table 1 of this paper which are identified as Cu IV in [7] but which, on my evidence, belong to Cu III. They have been examined individually with great care in all available exposures. It is possible that a few of the lines in my list may be partly IV and partly III, but it can only be a very small number.

In the course of examining the question of the origin of lines, I made a complete square array of the Cu IV analysis. On that diagram I marked all the questionable lines and it then appeared that a considerable number of levels must be spurious. To be certain of the whole analysis, it would be necessary to make a completely new and more accurate description of the spectrum, but from the diagram some examples can be given. The $^5P_3$ at 139604 may be correct, but its accompanying $^5P_2$ and $^5P_1$ are based on many lines included in my various categories above. The deletion of those 2 levels destroys the $^5S°_2$ at 204149 and all of the $^5D°$ at 214225 except $^5D°_4$.

As a second example, the $^3G_5$ at 140070 is probably correct, but $^3G_4$ and $^3G_3$ must be spurious and they, in turn, make many of the odd levels based on the ^2G term of Cu V very doubtful, indeed. A very dubious level is the ^1G at 148885 which includes four Cu III lines among its few combinations. The two even ^3P terms are both dubious and they lead to doubt about the odd terms based on the same ion terms. The highest ^3D term includes four Cu III lines amongst its rather few combinations.

From all the evidence I can only conclude that the Cu IV spectrum should be re-examined in its entirety.

6. Conclusion

In spite of the fact that the analysis of Cu III presented in this paper has been worked on for so many years, it is obviously incomplete and it is disappointing that some lines of considerable strength remain unclassified. Perhaps it is inherent in the kind of source that one must use to excite spectra above the second that it suppresses the less probable transitions and makes high levels very difficult to find. As an example, one can contrast the many transitions of the *ng* levels in Ni II with the great paucity of such transitions in Cu III. If it becomes possible to devise sources which overcome such difficulties, Cu III will have to be more completely observed and analysed by someone else, not me, and this paper will then serve as a useful guide.

7. References

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Publications of the National Bureau of Standards*

Citations with Selected Abstracts

J. Res. Nat. Bur. Stand. (U.S.), **79A** *(Phys. and Chem.)*, No. 2 (Mar.-Apr. 1975), SD Catalog No. C13.22/sec.A:79/2.

Thermal conductivity of gases. III. Some values of the thermal conductivities of argon, helium, and nitrogen, from 0 °C to 75 °C at pressures of 1×10^5 to 2.5×10^7 pascals, L. A. Guildner.

On the differential cross section for x-ray inelastic scattering, M. Kuriyama.

Simplification of van der Poel's formula for the shear modulus of a particulate composite, J. C. Smith.

The enthalpies of combustion and formation of nicotinic acid and creatinine, W. H. Johnson.

Simultaneous measurements of specific heat, electrical resistivity, and hemispherical total emittance by a pulse heating technique: hafnium-3 (wt %) zirconium, 1500 to 2400 K, A. Cezairliyan and J. L. McClure.

Heat capacities of polyethylene. III. One linear and one branched sample from 5 to 350 K, S-S. Chang, E. F. Westrum, Jr., and H. G. Carlson.

Monogr. 143. **Analysis of optically excited mercury molecules,** R. E. Drullinger, M. M. Hessel, and E. W. Smith, Nat. Bur. Stand. (U.S.), Monogr. 143, 51 pages (Jan. 1975) SD Catalog No. C13.44:143, $1.10.

Key words: dissociation laser; excimers; excited state kinetics; *f*-values; mercury molecules; new spectroscopic techniques; optical excitation; potential curves.

The Hg_2 molecule is representative of a class of molecules which have dissociative ground states and bound excited states. It can therefore be used as a prototype of this class of molecules which are of interest as potential new laser candidates. Because of the nonbound ground state, standard absorption spectroscopic techniques cannot be used to obtain the necessary information about the excited states. We have therefore developed new measurement techniques to obtain potential curves, *f*-values, and kinetic behavior for Hg_2. These techniques are applicable to this whole class of dissociation molecular systems.

Monogr. 148. **The role of standard reference materials in measurement systems,** J. P. Cali, T. W. Mears, R. E. Michaelis, W. P. Reed, R. W. Seward, C. L. Stanley, H. T. Yolken, and H. H. Ku, Nat. Bur. Stand. (U.S.), Monogr. 148, 54 pages (Jan. 1975) SD Catalog No. C13.44:148, $1.15.

Key words: certification; meaningful measurement; measurement; measurement system; precision; reference method; specificity; SRM; standard reference material; systematic error.

This publication is a guide to the use of Standard Reference Materials (SRM's) and should be useful to all users of SRM's, particularly those in countries developing national measurement systems. It is not intended to be an exhaustive description of the NBS-SRM program, but rather a review of the role SRM's play in the measurement system, how SRM's are certified, and what the certification means. To illustrate the use of SRM's several selected industries are described in which SRM's have made significant contributions.

SP400-5. **Semiconductor measurement technology: Measurement of transistor scattering parameters,** G. J. Rogers, D. E. Sawyer, and R. L. Jesch, Nat. Bur. Stand. (U.S.), Spec. Publ. 400-5, 53 pages (Jan. 1975) SD Catalog No. C13.10:400-5, $1.10.

Key words: electronics; high-frequency probes; interlaboratory comparison; scattering parameters; S parameters; transistors.

Results of an interlaboratory comparison of transistor scattering-parameter measurements are reported for transistor types 2N709, 2N918 and 2N3960. From these results it is estimated that, for such devices, between-laboratory variability of transistor S-parameter measurements in the frequency range between 200 and 2000 MHz could be held to a maximum relative sample standard deviation of 7.5 percent in the measurement of magnitude and a maximum sample standard deviation of 8 degrees in the measurement of phase of s_{11} and 3.5 degrees in the measurement of phase of other S parameters. This could be done if all participants were required to use the same calibration procedure and to limit their test signal to a level that would assure small-signal operation. In a separate study, the equivalent circuit of high-frequency probes used in characterizing the parameters of integrated circuits was evaluated by measuring S parameters at the input connectors with the probe tips in contact with known loads. These measurements revealed a resonance which would limit the usefulness of the probes for measurements in the vicinity of 1.2 GHz. Work is underway to determine design changes needed to eliminate this resonance.

SP400-8. **Semiconductor measurement technology. Quarterly report, April 1 to June 30, 1974,** W. Murray Bullis, Ed., Nat. Bur. Stand. (U.S.), Spec. Publ. 400-8, 70 pages (Feb. 1975) SD Catalog No. C13.10:400-8, $1.30.

Key words: Boron redistribution; Darlington pairs; dopant profiles; electrical properties; electronics; epitaxial layer thickness; flying-spot scanner; gold-doped silicon; hermeticity; measurement methods; microelectronics; micrometrology; MOS devices; oxide films; photomasks; photoresist; resistivity; scanning electron microscopy; semiconductor devices; semiconductor materials; semiconductor process control; silicon; spreading resistance; test patterns; thermal resistance; thermal response; thermally stimulated capacitance; thermally stimulated current; ultrasonic bonding; voltage contrast mode; wire bonds.

This quarterly progress report describes NBS activities directed toward the development of methods of measurement for semiconductor materials, process control, and devices. The emphasis is on sil-

*Publications with prices and SD Catalog numbers may be purchased directly from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (foreign: one-fourth additional). Microfiche copies of the above, plus paper copy and microfiche versions of NBS Interagency Reports (NBSIR's), may be purchased from the National Technical Information Service (NTIS), Springfield, Va. 22161. Prices are subject to change. Reprints from the NBS Journal of Research and non-NBS publications may often be obtained directly from the authors.

icon device technologies. Principal accomplishments during this reporting period include (1) identification of surface preparation procedures which improve the quality of spreading resistance measurements, (2) preparation of a videotaped tutorial discussion of thermally stimulated current and capacitance measurements, (3) completion of an analysis of the apparent position of an opaque edge when viewed with incoherent and coherent illumination, and (4) completion of the construction of a flying-spot scanner. Results are also reported on capacitance-voltage and two-probe resistivity measurements; analyses of thermally stimulated current and capacitance measurements on metal-oxide-semiconductor (MOS) capacitors; a review of methods for characterizing interface states associated with thin oxide films on silicon; fabrication of a test pattern based on the charge-coupled device; a preliminary comparison of filar and image shearing eyepieces for line-width measurement; a review of technologies in use for photomask inspection and measurements; procedures for determination of correct photoresist exposure; epitaxial layer thickness; scanning electron microscopy; mathematical modeling of ultrasonic bonding; leak test procedures; thermal resistance measurements on transistors and Darlington pairs, and transistor thermal response measurements. Supplementary data concerning staff, publications, workshops and symposia, standards committee activities, and technical services are also included as appendices.

TN594-9. **Optical radiation measurements: Describing spectrophotometric measurements,** W. H. Venable, Jr., and J. J. Hsia, Nat. Bur. Stand. (U.S.), Tech. Note 594-9, 49 pages (Nov. 1974) SD Catalog No. C13.46:594-9, $1.10.

Key words: accuracy; appearance; colorimetry; definition of spectrophotometry; error analysis; photometry; radiation transfer; reflectance; scattering; spectrophotometry; transmittance.

A general method is presented to describe spectrophotometric measurements mathematically. All space is divided into instrument space or sample space. Idealized absolute and relative measurements are defined at the boundary between the instrument and sample space by four descriptors: a radiance input L, a scattering function S, a relative responsivity R, and a scaling function K. Real measurements are also defined at the boundary and described by these four descriptors, and general expressions for fractional error are derived. A 45-degree, 0-degree reflectance measurement is used as a specific example to illustrate an application of this method to describing measurements and performing an error analysis.

TN850. **Gasoline and gasoline container fire incidents,** E. A. Tyrrell, Nat. Bur. Stand. (U.S.), Tech. Note 850, 34 pages (Jan. 1975) SD Catalog No. C13.46:850, 85 cents.

Key words: accidents; FFACTS; gasoline; gasoline containers; gasoline incidents; gasoline-related fires; ignition-causing activities; ignition sources; volatile flammable liquids; volatile flammable liquids incidents.

Gasoline was involved in 72 percent of the 645 volatile flammable liquids fire incidents found in the NBS Flammable Fabrics Accident Case and Testing System as of December 1973. These gasoline incidents, particularly those that were container-related, were studied in detail. Male victims out-numbered females approximately 5 to 1. Both males and females, ages 6-20, were injured more frequently than would have been expected if the incidents for each sex had been distributed uniformly over all age groups. Starting or tending an open fire caused ignitions most frequently and involved primarily males ages 13-45. Children were injured most from knocking over or dropping a container of gasoline close to an ignition source and playing with gasoline and an ignition source. Matches were the most frequent ignition source. Containers ranged from large gasoline cans to kitchen measuring cups, although gasoline cans were reported most often. The youngest children were involved most with some of the largest containers. The remaining victims were involved primarily with smaller, more easily managed containers. There was no indication that the gasoline containers, by themselves, contributed substantially to these incidents. The problem was one of human error—misuse or abuse of the gasoline, the container, or both.

TN855. **An experimental technique for the evaluation of thermal transient effects on piezoelectric accelerometers,** C. F. Vezzetti and P. S. Lederer, Nat. Bur. Stand. (U.S.), Tech. Note 855, 48 pages (Jan. 1975) SD Catalog No. C13.46:855, $1.05.

Key words: accelerometer; performance characteristics; piezoelectric; test method; thermal radiation; thermal transient; zero shift.

A simple, inexpensive method was developed for determining the effects of thermal transients on the zero output and sensitivity of piezoelectric accelerometers. Thermal transient stimuli are generated by an incandescent lamp and can be made to heat the top or side of the test accelerometer. Fourteen commercial accelerometers were tested using this technique. Zero shifts with magnitudes as high as 640 g_n* were observed. Zero shifts up to 2 percent of full-scale resulted from one-second duration transients, and up to 7 percent of full-scale from fifteen-second transients. These results were obtained at a radiation power density of 1.8 W/cm². No changes of accelerometer sensitivity exceeding experimental uncertainties were noted as a result of the thermal transients used.

TN856. **Note on a vibratory phenomenon arising in transducer calibration,** R. Kraft, Nat. Bur. Stand. (U.S.), Tech. Note 856, 13 pages (Feb. 1975) SD Catalog No. C13.46:856, 65 cents.

Key words: boundary initial problems; measurement; pressure transducer; transducer calibration; vibration.

By making appropriate physical approximations and idealizations a theoretical explanation is found for a vibratory phenomenon observed in calibrating pressure transducers inside thin liquid filled cylinders. The theoretical explanation requires proving the equivalence of two boundary initial problems which define the vibratory phenomenon. A short, general and complete proof of this equivalence is given.

NBSIR 74-449. **Fire endurance tests on walls and plumbing chases containing either metallic or nonmetallic drain waste and vent systems,** W. J. Parker, 83 pages (Nov. 1973). Order from NTIS as COM 75-10049, $4.75.

Key words: ABS; cast iron; copper; drain; fire endurance; fire spread; fire test; Operation BREAKTHROUGH; plastic pipe; PVC; smoke; toxic gases; vent; waste.

Two full scale non-load bearing ASTM E-119 fire endurance tests were performed on plumbing chase and wall assemblies containing polyvinyl chloride (PVC) drain, waste, and vent (DWV) systems typical of installations serving two or more stories. For the systems tested which were typical of kitchen sink drain systems constructed and installed according to typical plans, the PVC piping did not contribute to the spread of fire through the plumbing chase to the adjoining dwelling during the test which lasted 50 minutes. A test failure not associated with the plastic piping aborted the test but there was no indication that there would have been a failure due to the piping if the test had continued for one hour.

Three full scale non-load bearing ASTM E-119 fire endurance tests were also run on walls with enclosed DWV systems of acrylonitrile butadiene styrene (ABS), PVC, copper, and iron.

Neither PVC nor ABS piping contributed to fire spread in a plumbing system consisting of 2-inch stacks and 1-1/2-inch back-to-back laterals in a 2 × 6 fir-stud-and-gypsum-board wall. In one test in which the stacks and laterals were 4 inches in diameter and in another test in which the distance between wall surfaces was decreased by using 2 × 4 studs, the effective fire endurance rating of the wall assembly was reduced by the installation of the plastic plumbing.

This progress report on the fire endurance evaluation of five plumbing chase and wall assemblies is limited to construction assemblies in which the openings around the laterals were carefully sealed with plaster spackling. Additional tests are in progress to examine the effect of leaving the openings unsealed.

NBSIR 74-530. **Preparation of charcoal sampling tubes containing known quantities of adsorbed solvents,** B. C. Cadoff, E. E. Hughes, R. Alvarez, and J. K. Taylor, 36 pages (July 1974). Order from NTIS as COM 75-10041, $3.75.

Key words: activated carbon; air sampling; gas standards; industrial hygiene.

The method in widespread use for the determination of the concentration of organic solvents in the work atmosphere consists in collection of the solvent by adsorption on activated charcoal followed by desorption with carbon disulfide and measurement by gas chromatography. This report describes techniques developed to produce reference standards for this determination and modifications in the analytical procedure to improve its precision and accuracy.

NBSIR 74-553. **Preparation and calibration of phosphor standards,** M. L. Greenough and H. K. Hammond, III, 70 pages (Oct. 1974). Order from NTIS as COM 75-10058, $4.25.

Key words: fluorescence measurement; instrumentation, luminescence measuring; luminescence measurement; phosphorescence measurement.

This project involved two activities, 1) the fabrication and calibration of phosphor standards for use in the Postal Service Model 4A8 Phosphormeter and 2) the construction of an instrument to perform the calibration function. Both of these relate to the standardization of the phosphorescent and fluorescent activity of the luminescent coatings applied to postage stamps by the Bureau of Engraving and Printing. The purpose of the luminescent coatings is to facilitate detecting the orientation of envelopes in facer-canceler machines during mail processing.

Work on the project entailed the fabrication of approximately 60 phosphor standards, which are hand-sized aluminum blocks into which stamp-sized wafers of luminescent materials are mounted. Fabrication was carried out following the specific procedures supplied by the Postal Service, with however, authority to verify or alter the process as necessary. On the other major project effort, an instrument was designed and constructed following in general the basic design of an earlier breadboard device developed under a prior project. Quantitatively in the system, evaluations are ultimately referred to calibrations at NBS of the relative irradiance of a lamp in the ultraviolet and visible regions of the spectrum.

This report, one of two covering the project activities, describes the preparation of luminescent wafers, their assembly into phosphor standards and the test procedures on completed standards. It includes a tabulation of the calibrated values of the new standards.

NBSIR 74-583. **The role of passive film growth kinetics and properties in stress corrosion and crevice corrosion susceptibility,** J. Kruger and J. R. Ambrose, 88 pages (Sept. 1974). Order from MTIS as AD 767326, $4.75.

Key words: chloride; crevice corrosion, ellipsometry failure prediction; molybdenum; repassivation kinetics; stainless steels; stress corrosion; testing techniques.

A study of the effect of alloying chromium and molybdenum in ferritic stainless steels has been made using techniques to study repassivation kinetics (tribo-ellipsometry) and depassivation kinetics (a recently developed ellipsometry technique for studying optical changes occurring within a crevice). Results indicate that chromium additions affect both repassivation and depassivation processes while molybdenum appears to affect only the repassivation processes. A discussion is given of a generalized mechanism for localized corrosion which postulates that susceptibility to attack is determined by the competition between depassivation and repassivation processes.

Constant strain rate studies were performed using AISI 304 stainless steel exposed to acidified 1.ON NaCl solution (pH = 3.0). In this particular environment, repassivation kinetics measurements using the tribo-ellipsometric technique had shown that the metal dissolution rates were rather large due to reduced film repair kinetics, indicating the possibility of susceptibility to stress corrosion cracking (SCC). Reduced time to failure and maximum sustained load at a one strain rate suggest a relationship between SCC, repassivation kinetics, and rate of pure metal production.

A review of current approaches to the study of stress corrosion and a discussion of how these approaches can lead to new failure prediction tools is given.

NBSIR 74-588. **Development of a bench test for Type X core gypsum board,** J. L. Houser, 26 pages (Dec. 1974). Order from NTIS as COM 75-10040, $3.75.

Key words: building codes; construction materials; fire endurance ratings; fire tests; gypsum.

This paper describes the development of a test method for determining that the core material in a gypsum board sample qualifies as Type X. A 2 inch (5.08 cm) by 16 inch (40.64 cm) specimen is flexurally stressed during the test by suspending a weight from the cantilevered end of the test sample. The specimen is swiveled into the center of a two burner turbulent flame at an average temperature of 1,780 °F (971 °C). The burners are positioned from above and below. The test is terminated when the specimen either breaks or deflects through an arc three times the specimen thickness. Results show this method to be repeatable with a coefficient of variation equal to ±8 percent for a given type of material from a single manufacturer.

NBSIR 74-602. **Efficient methods of extreme-value methodology,** J. Lieblein, 32 pages (Oct. 1974). Order from NTIS as COM 75-10048, $3.75.

Key words: distribution of largest values; efficient estimators; extreme values; linear unbiased estimators; statistics; Type I distribution.

This report presents the essentials of modern efficient methods of estimating the two parameters of a Type I extreme-value distribution. These methods are an essential phase of the analysis of data that follow such a distribution and occur in the study of high winds, earthquakes, traffic peaks, extreme shocks and extreme quantities and phenomena generally. Methods are given that are appropriate to the quantity of data available—highly efficient methods for smaller samples and nearly as efficient methods for large or very large samples. Necessary tables are provided. The methods are illustrated by examples and summarized as a ready guide for analysts and for computer programming. The report outlines further work necessary to cover other aspects of extreme-value analysis, including other distribution types that occur in failure phenomena such as consumer product failure, fatigue failure, etc.

NBSIR 75-637. **Note on simplified estimators for type I extreme-value distribution,** J. Lieblein, 14 pages (Dec. 1974). Order from NTIS as COM 75-10055, $3.25.

Key words: bias; efficiency; extreme values; linear unbiased estimators; simplified estimators; statistics; type I distribution.

Methods for extreme-value analysis (for the Type I extreme-value distribution) that have optimum properties involve up to 20 quantities (depending on sample size) whose values are known to 6 decimal places. The present note shows how to modify these to much simpler values involving 2 decimal places that are more convenient to use yet sacrifice very little of the optimum features.

This column lists all outside publications by the NBS staff, as soon after issuance as practical. For completeness, earlier references not previously reported may be included from time to time.

Adair, R. T., Hoer, C. A., Kamper, R. A., Simmonds, M. B., **RF attenuation measurements using quantum interference in superconductors,** (Proc. 1974 Conf. on Precision Electromagnetic Measurements, London, England, July 1-5, 1974), Abstract in *CPEM Digest No. 113*, 4-5 (Institution of Electrical Engineers, London, England, 1974).

Key words: Josephson junction; quantum interference; rf attenuation; superconductivity.

A unique portable system has been developed for measuring rf attenuation over a dynamic range of 65 dB at 30 MHz. A Superconducting QUantum Interference Device (SQUID) is the basis of the system.

Measurements made with this system have an rms deviation from the NBS National Reference Standard of ± 0.002 dB.

A SQUID is a loop of superconducting metal closed by a Josephson junction, operating in liquid helium. It converts variations in magnetic flux to periodic variations in impedance which are sensed at microwave frequencies. This provides a convenient, natural means of measuring electrical quantities such as voltage, current, power and attenuation.

Alvarez, R., **Sub-microgram per gram concentrations of mercury in orchard leaves determined by isotope dilution and spark-source mass spectrometry,** *Anal. Chim. Acta* **73,** 33-38 (1974).

Key words: agriculture; environment; isotope dilution; mass spectroscopy; NBS Standard Reference Material; orchard leaves; trace mercury.

A stable isotope dilution procedure in conjunction with the spark source mass spectrograph was developed for determining sub-μg g^{-1} concentrations of mercury in orchard leaves. A 5-g sample was spiked with a solution of mercury, isotopically enriched in ^{201}Hg and ^{198}Hg served as a carrier. After wet-ashing the sample with nitric and perchloric acids under reflux and distilling most of the acid, the isotopically equilibrated mercury was electrodeposited onto high-purity gold wires for sparking in the mass spectrograph. The concentration was calculated from the altered isotope ratio, ^{201}Hg/^{202}Hg, and other data. The results were compared with those obtained by atomic absorption spectrometry and neutron activation, leading to a certified value of 0.155 ± 0.015 μg g^{-1} for the mercury content of Orchard Leaves, SRM 1571 of the National Bureau of Standards.

Andrews, J. R., **Precision picosecond pulse measurements using a high quality superconducting delay line,** (Proc. 1974 Conf. on Precision Electromagnetic Measurements, London, England, July 1-5, 1974), Abstract in *CPEM Digest* No. 113, 316-318 (Institution of Electrical Engineers, London, England, 1974).

Key words: delay line; picosecond; pulse measurement; superconductivity.

With the aid of a high quality superconducting delay line, it is now possible to perform direct oscillographic measurements of the picosecond transition times of very fast electrical signals that do not furnish pretriggers. A 15 meter superconducting delay line has been constructed. It has an attenuation of 14 dB/km at 1 GHz. The 10 percent-90 percent transition time of this line and its associated air lines leading into and out of the liquid helium dewar is 18 ps. Some applications of this delay line are shown. They include the measurement of the pulse outputs from mercury switch and spark gap pulse generators and the transient response of a traveling wave oscilloscope.

Arp, V., **New forms of state equations for helium,** *Cryogenics* **14,** No. 11, 593-598 (Nov. 1974).

Key words: enthalpy; entropy; equations of state; helium; pressure.

Accurate helium properties must be measured to develop refrigeration systems for superconducting motors and generators. Normally when measuring these properties a double iteration is necessary on the equation of state to find density and temperature. In this paper new state equations are developed which eliminate iterative procedures. These equations are subsets of three overlapping sets of reference equations. They are thermodynamically inconsistent to the reference equations by a small degree of error, but have been found useful for many calculations.

Ayres, R. L., Cavallo, L. M., Coursey, B. M., Hutchinson, J. M. R., Mann, W. B., **National Bureau of Standards gamma-ray standards and techniques for gamma-ray measurements, (Abstract),** *Proc. Trans. 1973 Annual Meeting of the American Nuclear Society, Chicago, Ill., June 10-14, 1973,* **16,** 69 (1973).

Key words: energy efficiency curves; gamma ray; mixed radio nuclide; standards.

The National Bureau of Standards provides gamma-ray standards in a number of forms for different purposes. Our earliest standards were solution standards of various gamma-ray-emitting radionuclides. These were later supplemented by point-source standards covering the range of photon energies from 60 keV to 2.61 MeV. Currently we are also issuing mixed-radionuclide solution standards, each covering the photon energy range from about 88 keV to 1.84 MeV.

The values of most of our gamma-ray standards are preserved on calibrated atmospheric-air and pressurized-argon ionization chambers. Efficiency-energy curves for these chambers have been accumulated over a great many years, based on data collected by direct methods of measurement such as coincidence counting. Cesium-137 and ^{85}Kr standards were produced, respectively, by means of the ion chamber, using efficiency interpolation, and by comparison with ^{85}Sr standards. The mixed-radionuclide, gamma-ray solution standards were primarily designed for the calibration of detectors used in measuring power reactor effluent, and are issued in bottles of standard dimensions.

Beatty, R. W., **2-port standards for evaluating automatic network parameter measurement systems,** (Proc. 1974 Conf. on Precision Electromagnetic Measurements, London, England, July 1-5, 1974), Abstract in *CPEM Digest No. 113*, 87-89 (Institution of Electrical Engineers, London, England, 1974).

Key words: automatic measurement; coaxial standards; network parameters; reflection coefficient; scattering coefficients; transmission coefficient; waveguide standards; 2-port standards.

2-port standards have been developed for evaluating the performance of automatic systems which measure network parameters over a broad frequency range.

The standards consist of short sections of coaxial line or waveguide which include or produce simple discontinuities. One can calculate the complex reflection and transmission coefficients for any frequency given the dimensions.

In use, the standards are terminated by a port of the measurement system which is made effectively non-reflecting by means of a calibration procedure and computer correction.

A number of types of standards are described and measurements with a typical automatic system are presented.

Blevin, W. R., Geist, J., **Infrared reflectometry with a cavity-shaped pyroelectric detector,** *Appl. Opt.* **13,** No. 10, 2212-2217 (Oct. 1974).

Key words: directional-hemispherical; polyvinyl fluoride; pyroelectric detectors; reflectance.

A new type of reflectometer has been developed for measuring directional-hemispherical spectral reflectances in the infrared region. The instrument is based upon a cavity-shaped pyroelectric detector that itself collects the radiation reflected by the test sample, thereby obviating the need for an intermediate collector such as an integrating sphere or concave mirror. This detector is made from an electrically polarized plastic film of polyvinyl fluoride, coated with gold-black on its inner surface and backed with brass shim on its outer surface in order to provide mechanical strength. The reflectometer has been used with a Fourier spectrometer to measure spectral reflectances over the wavelength range 5-30 μm.

Boettinger, W. J., **The structure of directionally solidified two-phase Sn-Cd peritectic alloys,** *Met. Trans.* **5,** 2023-2031 (Sept. 1974).

Key words: alloy; directional solidification; incongruent melting alloy; peritectic reaction; Sn-Cd alloys; structure.

The structure of Sn-Cd two-phase peritectic alloys directionally solidified at various values of G/v (temperature gradient in the liquid divided by growth rate) is reported. The minimum value of G/v as a function of composition required for the solidification of two-phase peritectic alloys with a planar liquid-solid interface is estimated using a simple constitutional super-cooling stability criterion. At a value of G/v just below this minimum value, these alloys solidify with a non-planar interface consisting of cells of α (the high temperature phase) and intercellular β (the low temperature phase). This produces a coarse rod-like microstructure consisting of rods of α phase imbedded in a β matrix. At a value of G/v above this minimum value, these alloys solidify with a planar interface which alternately deposits bands of α and β transverse to the growth direction. No coupled growth of α and β at a planar interface is observed in Sn-Cd two-phase peritectic alloys as was expected. To understand this, an analysis of coupled (eutectic-like) growth of two-phase peritectic alloys is presented and contrasted with the results of the Jackson-Hunt theory of lamellar eutectic growth. This calculation indicates that the coupled growth of two-phase peritectic alloys is unlikely on theoretical grounds.

Bridges, J. M., Kornblith, R. L., **ARC measurements of Fe I oscillator strengths,** *Astrophys. J.* **192,** 793-812 (Sept. 15, 1974).

Key words: arc; f-values; iron and oscillator strengths.

Oscillator strengths for 534 lines of Fe I have been measured from a wall-stabilized arc. These lines have wavelengths between 2900 and 5800 Å and cover a wide range in intensity and upper energy level. Lifetime values were used in normalizing to an absolute scale and in determining the arc temperature. This temperature agreed with that found independently, using LTE plasma diagnostics. Comparisons with other recent oscillator strength measurements generally show agreement within combined error estimates.

Carrington, C. G., Gallagher, A., **Blue satellite bands of Rb broadened by noble gases,** *Phys. Rev. A* **10,** No. 5, 1464-1473 (Nov. 1974).

Key words: line-broadening; rubidium; satellite.

Measurements are presented for the blue-wing satellite bands of the Rb first resonance line (780 nm) emitted in the presence of the noble gases Ne, Ar, Kr, and Xe. The continuum intensity per spectral interval and perturber density is expressed as a fraction of the total Rb (780 nm) fluorescence from optically thin vapor. Over the $\sim 10^{18} - 10^{19}$ cm^3 density range investigated this normalized satellite-peak intensity is found to scale linearly with perturber density and approximately exponentially in $-1/T$, T being the absolute temperature. In the classically forbidden region beyond the satellite peak the intensity drops exponentially with frequency for Xe perturbers, but departs from exponential behavior in the Ar and Kr data. We observe undulations in the spectra between line center and the satellite. This is expected due to the possibility of interference between contributions to the transition probability at two internuclear separations, the separations at which the difference potential equals the photon energy.

Carter, G. C., Kahan, D. J., **NMR, soft x-ray, and other physical properties of rare earth metals and alloys—an annotated bibliography,** (Proc. 11th Rare Earth Research Conference, Traverse City, Mich., Oct. 7-10, 1974), Paper in *Proceedings of the 11th Rare Earth Research Conference,* J. M. Haschke and H. A. Eick, Eds., **II,** 1014-1018 (1974).

Key words: alloy data; bibliography; index; Knight shifts; NMR; rare earth metals and alloys; soft x ray.

The Alloy Data Center (ADC) has deep-indexed about 18,000 papers dealing with physical properties of metals and alloys, and maintains these in a computerized file. Of these, approximately 3,000 contain information on transuranic or rare earth metals (including Sc, Y, La), or alloys with one or more such components. These literature references have been printed out alphabetically by chemical symbol to form a rare-earth annotated bibliography, which is available as an NBS Special Publication. The ADC collects all nuclear magnetic resonance (NMR) and soft x-ray spectroscopy (SXS) papers, and many papers dealing with other electronic-structure related properties as well. This bibliography, therefore, contains all NMR and SXS papers for rare-earth related metallic materials. The ADC does not intend to compete with the Rare Earth Information Center, which is far more comprehensive for many other physical properties of rare earth materials. Rather, this bibliography of the ADC's holdings is thought to represent a valuable bibliographic tool in the interim period until the Rare Earth Information Center has completed its conversion to an automated system.

Cavallo, L. M., Schima, F. J., Unterweger, M. P., **Decay of $^{133}Xe^g$,** *Phys. Rev. C* **10,** No. 6, 2631-2632 (Dec. 1974).

Key words: enriched source; Ge(Li) detector; measured $T_{1/2}$; pressured ionization chamber; radioactivity $^{133}Xe^g$; ν relative intensity.

The half-life of isotopically separated $^{133}Xe^g$ was determined by measurement in a $4\pi\gamma$ pressure ionization chamber. The value obtained was 5.245 days with an uncertainty of 0.006 days which is the linear sum of the standard error at the 99 percent confidence limit and the estimated systematic errors. This result was confirmed by two separate half-life measurements employing a Ge(Li) detector. The γ rays which deexcite the level at 383 keV in ^{133}Cs have been observed. The intensities of the 383- and 221-keV γ rays relative to the 302-keV γ ray intensity were found to be 0.489 and 0.020 with the respective standard errors calculated to be 3.8 percent and 40 percent.

Choi, C. S., Bulusu, S., **The crystal structure of dinitropentamethylenetetramine (DPT),** *Acta Crystallogr. B30,* Part 6, 1576-1580 (June 1974).

Key words: crystal structure; cyclic nitramine; organic compound.

The crystal structure of dinitropentamethylenetetramine, or DPT, $C_5H_{10}N_6O_4$, has been studied by using three-dimensional x-ray (Mo $K\alpha$) diffraction data. The unit cell is monoclinic $P2_1/c$, with $a = 9{\cdot}345$ (5), $b = 8{\cdot}284$ (5), $c = 11{\cdot}566$ (5) Å, $\beta = 105{\cdot}6$ (1)° and $Z = 4$. The structure was solved by direct methods and refined by full-matrix least-squares methods to a final $R = 0{\cdot}035$, $R_w = 0{\cdot}037$. The two N-NO_2 groups in a DPT molecule are planar, with the two nitramine carbons out of the plane. The molecule has approximate mirror symmetry bisecting each of the two nitro groups.

Collin, G. J., **Photolyse du butène-1 dans l'ultraviolet à vide,** *Can. J. Chem.* **51,** No. 17, 2853-2859 (1973).

Key words: far ultraviolet; free radical reactions; ion-molecule reactions; photochemistry; primary processes; 1-butene.

The vacuum u.v. photolysis of 1-butene was studied in the 147-105 nm region. The main products formed from the fragmentation of excited molecules are allene, 1,3- and 1,2-butadienes, ethylene, and acetylene. The addition of a hydrogen atom to the double bond produces mainly secondary butyl radicals (91%) at 147 nm. At 123.6 nm, this proportion becomes 82 percent. Thus at shorter wavelengths (10 and 11.6-11.8 eV), hydrogen atoms are produced with a kinetic energy higher than the thermal energy.

Cook, R. K., **Paraholography—a new method for measurement of the directional distribution of sound waves in a reverberation chamber,** *J. Acoust. Soc. Amer.—Technical Notes and Research Briefs* **56,** No. 4, 1305-1307 (Oct. 1974).

Key words: acoustics; acoustical holography; acoustical measurement; paraholography; reverberation chambers; sound propagation.

We describe a method for experimental determination of the complex of plane waves composing the sound field in a reverberation chamber. The basic holographic principle is comparison of the actual sound field with a family of reference plane waves having precisely known directions of propagation, sound pressures, and phases. The reference waves are not "real" waves but are created electronically, on the electrical side of microphones sensing the actual sound field, so as to be "parallel" to real waves.

Cook, R. K., Schade, P. A., **New method for measurement of the total energy density of sound waves,** (Proc. 1974 International Noise Control Engineering Conference, Washington, D.C., Sept. 30-Oct. 2, 1974), Paper in *Inter-Noise 74 Proceedings*, J. C. Snowdon, Ed., pp. 101-106 (Inter-Noise 74, Institute of Noise Control Engineering, Poughkeepsie, N.Y., 1974).

Key words: acoustical measurements; acoustics; noise measurement; reverberation chambers; sound energy measurement; sound power measurement.

The total energy of a sound field in reverberation chambers is usually sampled by an array of microphones. Each measures the time-average of the squared sound pressure at its location. This is equivalent to sampling the time-average of the *potential* energy density of the sound field. It would be advantageous to measure as well the time-averaged squared particle velocity. This would yield the *kinetic*-energy density, which added to the *potential*-energy density would then yield the *total*-energy density. A principal advantage of the total energy density is that its spatial variance is in general appreciably less than the potential variance. We find this from an analysis of the variances for the eigenmodes of rectangular chambers having reflecting (rigid) walls. A microphone for total energy density can be made from a spatial array of six elements arranged at the corners of a regular octahedron. Electret microphones seem to be particularly suitable for the elements. The total energy density can be computed from the sums and differences of the electret outputs, with the help of integrated circuits, and displayed as a running function of time, e.g., as a graphic recording. For a standing-wave tube, only two elements are needed, and the total-energy-density microphone then takes a very simple form.

Cowan, R. D., Radziemski, L. J., Jr., Kaufman, V., **Effect of continuum configuration interaction on the position of s p^6 in neutral chlorine and other halogens,** *J. Opt. Soc. Amer.* **64,** No. 11, 1474-1478 (Nov. 1974).

Key words: atomic spectra; chlorine; halogens; photoionization.

Ab initio Hartree-Fock calculations in the single-configuration approximation predict that the 3s $3p^6$ $^2S_{1/2}$ level of Cl I lies far above the ionization limit, although this level is observed to be the lowest of all even $J = 1/2$ levels other than $3s^2$ $3p^4$ 4s $^4P_{1/2}$, $^2P_{1/2}$. The solution of this anomaly lies in configuration interaction with the high-lying portion of the $3s^2$ $3p^4$ $\epsilon d\,^2S_{1/2}$ continuum, which is sufficiently strong to depress the computed s p^6 level to its observed position. This interaction with the continuum is an extension of the well-known interaction of sp^{w+1} with the discrete s^2p^{w-1} *nd* Rydberg series, and is important in all neutral third-row elements Al to Cl, as well as in Br and I and probably other fourth- and fifth-row elements. The effect is, however, somewhat smaller in Br I and I I than in Cl I, with the result that there exists no bromine nor iodine level that is primarily s p^6 in nature. The interactions produce large changes in computed transition probabilities and photoionization cross sections.

Crawford, M. L., **Generation of standard EM fields using TEM tranmission cells,** *IEEE Trans. Electromagn. Compat.* **EMC-16,** No. 4, 189-195 (Nov. 1974).

Key words: compatibility; standard fields; susceptibility; testing; transverse electromagnetic.

A new technique developed at the National Bureau of Standards (NBS) for establishing standard, uniform, electromagnetic (EM) fields in a shielded environment is described. The technique employs transverse electromagnetic (TEM) transmission cells that operate as 50 Ω impedance-matched systems. A uniform TEM field is established inside a cell at any frequency of interest below that for which higher order modes begin to propagate. Standard field strength levels from 10 μV/m to 500 V/m can be established with uncertainties of less than 1.0 dB to 2.0 dB inside the NBS cells for frequencies from dc to 500 MHz. The cells are especially useful for calibrating EM radiation hazard meters, for emission and susceptibility testing of small to medium sized equipment, and for special low level calibration of very sensitive field strength meters.

Das, E. S. P., deWit, R., Armstrong, R. W., Marcinkowski, M. J., **Kinks, jogs, and a regeneration mechanism for Volterra disclinations,** *J. Appl. Phys.* **44,** No. 11, 4804-4806 (Nov. 1973).

Key words: crystal; defect; disclination; dislocation; elasticity; jog; kink; multiplication; plasticity; Volterra.

A regenerative mechanism is proposed which can lead to unlimited multiplication of disclinations. This mechanism consists of a glissile segment of a disclination pinned by two sessile "jogs," and therefore is similar to a Frank-Read source for dislocations. It is also possible to have a U-mill, Z-mill, and L-mill for disclination multiplication. It is further shown that a single source can give rise to disclinations of opposite signs (and this allows rotation in both directions of that part of the crystal above the source, relative to the part below), depending upon the direction in which the source operates.

Davis, G. T., Weeks, J. J., Martin, G. M., Eby, R. K., **Cell dimensions of hydrocarbon crystals: Surface effects,** *J. Appl. Phys.* **45,** No. 10, 4175-4181 (Oct. 1974).

Key words: crystal surfaces; density; lamella thickness; paraffins; polyethylene; unit cell; x ray.

The unit-cell dimensions of a given polyethylene have previously been shown to vary nearly linearly with the reciprocal of lamella thickness. Data obtained at 153.2 and 296.2 K are presented to show that the slope of this dependence is different for crystals of orthorhombic *n*-paraffins, melt-crystallized polyethylene, and solution-crystallized polyethylene. Within the limits of error, all extrapolate to the same basal area at infinite lamella thickness, and this agrees with the measured value for sample crystallized from the melt under high pressure to yield a long period of about 3500 Å. Since the effect is a surface one, it is proposed that these differences result from the differences between methyl interactions, fold interactions, different fold planes, domains, etc. It is shown that the variation of cell dimension with lamella thickness leads to a quadratic term in the variation of macroscopic density. This term permits the separation of the thickness and density of a lower-density surface layer in a two-phase model.

Debye, N. W. G., Linzer, M., **Correlation of nuclear quadrupole resonance and ^{119m}Sn Mössbauer spectral parameters,** *J. Chem. Phys.* **61,** No. 11, 4770-4776 (Dec. 1974).

Key words: Mössbauer; NQR; nuclear quadrupole coupling; organotin; organometallic.

A precise redetermination of the ^{119m}Sn Mössbauer spectral parameters of a large number of organotin (IV) halides and of the tin (IV) tetrahalides has been made. The ^{35}Cl NQR resonance spectra of $(CH_3)_3SnCl$ and of $(n\text{-}C_5H_{11})_2SnCl_2$ have been measured for the first time. These data, in conjunction with literature values of other halogen frequencies in this series, yield correlations of both the central tin atom Mössbauer isomer shift and quadrupole splitting values with the reduced ligand NQR coupling constants. The correlations may be interpreted qualitatively in terms of the bonding trends expected on the basis of ligand electronegativities, and the uniformities of the correlations strongly indicate a lack of sharply defined structural variations within these compounds.

Durst, R. A., **Ion selective electrodes,** (Proc. Int. Conf. on Localized Corrosion, Williamsburg, Va., Dec. 6-10, 1971), Paper in *Localized Corrosion*, R. W. Staehle, B. F. Brown, J. Kruger, and A. Agrawal, Eds., pp. 151-157 (National Association of Corrosion Engineers, Houston, Texas, 1974).

Key words: electrode review; ion-selective electrodes; membrane electrodes; potentiometry.

The state of the art of the newer non-glass types of ion-selective electrodes is reviewed. This survey includes the theory, characteristics, and methodology of the solid-state, liquid ion-exchange and heterogeneous membrane electrodes.

The applications of these sensors to a wide variety of scientific disciplines is discussed, ranging from various physicochemical studies and biochemical research to industrial analysis and control systems. Since this field has been growing so rapidly in the past several years, only a few of the many applications of ion-selective electrodes are presented. Special emphasis is placed on the experimental ferric ion-selective electrode as a possible sensor in corrosion studies. Much remains to be done with these sensors in the very fruitful and socially relevant areas of environmental pollution and public health. Ion-selective electrodes can provide a wealth of information if used with the proper precautions and their usefulness is limited only by the imagination and ingenuity of the users.

Edgerly, D. E., **Are aerosol packages proliferated within the meaning of The Fair Packaging and Labeling Act?,** *Proc. 1969 Chemical Specialities Manufacturers Association 55th Annual Meeting, Washington D.C., Dec. 8-11, 1968,* pp. 68-69 (1968).

Key words: aerosols; Fair Packaging and Labeling Act; packages; proliferation; voluntary standardization.

The purpose of this presentation is to familiarize the manufacturers of aerosol packages with the undue proliferation provision of the Fair Packaging and Labeling Act, and Department of Commerce responsibilities in interpreting proliferation. The scope of the talk centers upon the application of the undue proliferation provision to aerosol packages offered for sale at retail. A discussion of the market of several aerosol products and their place in the retail outlet is considered in light of the consumer's ability to make value comparisons. Considerations of a technical and/or marketing nature are discussed in view of problems which affect voluntary standardization. Finally, and of great importance, the manufacturer's responsibility within the spirit of the Fair Packaging and Labeling Act is discussed.

Eisenhart, C., **Karl Pearson,** Paper in *Dictionary of Scientific Biography,* **X,** 447-473 (Charles Scribner's Sons, New York, N.Y., 1974).

Key words: bibliography; *Biometrika*; Chi-square tests; correlation, regression; R. A. Fisher; Francis Galton; frequency curves, method of moments; Karl Pearson; statistics; *Tables for Statisticians and Biometricians*; W. F. R. Weldon.

A review of the life and work of Karl Pearson (1857-1936), founder of the science of statistics. His student days at Cambridge and in Germany. His pre-1890 career as a professor of applied mathematics and mechanics, as a philosopher of science, and as a social reformer. The role of Francis Galton and W. F. R. Weldon in redirecting his career to founder (1891-1936) of the science of statistics. Method of Moments and Pearson System of Frequency Curves; Correlation and Regression; Chi Square Tests. *Biometrika; Annals of Eugenics; The Treasury of Human Inheritance; Tables for Statisticians and Biometricians; Tracts for Computers; Tables of the Incomplete Γ-function; Tables of the Incomplete β-function.* Bibliography of principal Original Works; and of major Secondary Literature.

Ely, J. F., McQuarrie, D. A., **Calculation of dense fluid transport properties via equilibrium statistical mechanical perturbation theory,** *J. Chem. Phys.* **60,** No. 11, 4105-4108 (June 1, 1974).

Key words: argon; Barker-Henderson perturbation theory; modified Enskog theory; thermal conductivity; transport properties; viscosity.

The viscosity and thermal conductivity coefficients of dense fluid argon have been calculated using the modified Enskog theory and the equilibrium statistical mechanical perturbation theory of Barker and Henderson. Agreement with experimental transport data is shown to be, in general, quite good. The results of these calculations are also compared to those obtained using the modified Enskog theory and an experimental equation of state. In this case, the results are seen to be excellent, which indicates that this approach provides us with a method of predicting transport properties of simple dense fluids from fundamental molecular theory.

Eyler, J. R., Atkinson, G. H., **Dye laser-induced photodetachment of electrons from SH^- studied by ion cyclotron resonance spectroscopy,** *Chem. Phys. Lett.* **28,** No. 2, 217-220 (Sept. 15, 1974).

Key words: ion cyclotron resonance; mass spectrometry; negative ions; photodetachment; spin-orbit coupling; tunable dye laser.

The photodetachment of electrons from gaseous SH^- ions has been studied in an ion cyclotron resonance mass spectrometer using a flashlamp-pumped organic dye laser as a light source. The onset of the photodetachment process at 538.7 ± 0.3 nm ($2.301_6 \pm 0.001_3$ eV, 18563 ± 10 cm^{-1}) agrees well with that obtained in an earlier study. Coarse structure in the photodetachment curve with a spacing of 11.8 nm (0.052 eV, 422 cm^{-1}) has been identified with spin-orbit coupling in the SH· radical. Finer structure, with a spacing of ca. 2.5 nm (0.011 eV, 89 cm^{-1}), has also been observed in the curve, but remains unexplained.

Eyler, J. R., **Intracavity dye laser technique for the study of laser-induced ionic processes,** *Rev. Sci. Instrum.* **45,** No. 9, 1154-1156 (Sept. 1974).

Key words: intracavity technique; ion cyclotron resonance; mass spectrometry; negative ions; photodetachment; tunable dye laser.

An intracavity dye laser technique has been used to study the photodetachment of electrons from gaseous OH^- ions in an ion cyclotron resonance (icr) spectrometer. Enhancement of the photodetachment effect by a factor of 6.8 when comparing the intracavity technique to a double-pass experiment has been observed. Under the conditions of these experiments approximately 93 percent of the OH^- ions in the icr cell undergo photodetachment using the intracavity technique.

Farmer, B. L., Eby, R. K., **Methyl branches in hydrocarbon crystals: Calculation of relaxation effects,** *J. Appl. Phys.* **45,** No. 10, 4229-4238 (Oct. 1974).

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Key words: mechanical relaxation; methyl branches; paraffins; polyethylene; potential energy calculations; relaxation strength; two-site model.

A two-site model for a relaxation process has been used in conjunction with the results of illustrative potential-energy calculations on a model system to examine the effects of isolated methyl branches on the chain packing and mechanical relaxations of a linear hydrocarbon host crystal. The results indicate that a branched molecule can be accommodated in an array of linear chains in two different modes of packing and that each mode has two orientations. For one of the modes, the two orientations have nearly equal energies. Upon mechanical deformation of the array, this mode gives rise to a relaxation. The relative strengths are evaluated for different deformations, some of which yield values of the order of those observed experimentally. This relaxation is much weaker for unbranched chains in the planar zigzag conformation.

Geltman, S., **The Coulomb-projected Born approximation V. Ionization of helium,** *J. Phys. B* **7,** No. 15, 1994-2002 (1974).

Key words: electron impact; helium; ionization; theoretical study.

The triple differential cross section for the electron impact ionization of helium is calculated in the Coulomb-projected Born approximation, including exchange. Detailed comparison is made with the ordinary Born result and with available experiment in both the coplanar and non-coplanar geometries. The agreement with experiment in almost all cases is appreciably better for the Coulomb-projected Born results than for the ordinary Born results.

Gerola, H., Linsky, J. L., Shine, R., McClintock, W., Henry, R. C., Moos, H. W., **Evidence for a corona of Beta Geminorum,** *Astrophys. J.* **193,** No. 3, L107-L110 (Nov. 1, 1974).

Key words: stellar atmospheres; stellar coronae; ultraviolet stellar spectrum.

Using the Princeton spectrometer on the satellite *Copernicus*, a strong emission line has been detected in the K0 giant β Gem at 1218.4 Å, which is identified as the $^1S_0 - {}^3P^o_1$ intercombination line of O V. The strength of the line is such that it is probably formed in a corona at temperatures near 260,000 K rather than in an analog of the solar chromosphere-corona transition region.

Goldman, A. J., **Fractional container-loads and topological groups,** *Oper. Res. Letters to Editor* **16,** No. 6, 1218-1221 (Nov.-Dec. 1968).

Key words: inventory theory; topological groups.

The problem treated is that of finding those probability distributions of fractional "tails" on the input volumes to a unitization facility during successive time periods that yield a time-invariant distribution of backlog levels. It is shown that this reduces to the determination (which is carried out) of all closed subgroups of the circle group.

Goldman, A. J., **Optimal locations for centers in a network,** *Transp. Sci.* **3,** No. 4, 352-360 (Nov. 1969).

Key words: concave functions; networks; optimal locations.

The problem treated is that of locating n centers (processing facilities) in a network, so as to minimize the total transportation cost associated with their use. On the assumption that all movements occur between a vertex and a center nearest it, *HAKIMI* has shown that only vertex locations for the centers need be considered. The present paper shows that this conclusion remains valid under alternative assumptions more appropriate for some applications.

Goldman, A. J., **The minimax transportation problem,** *Transp. Sci. Letter to Editor* **2,** No. 4, 383-387 (Nov. 1968).

Key words: linear programming; network flows; single commodity; transportation; transportation problem.

This note demonstrates a simple solution method for the following single-commodity flow problem: Given a set of origins each with a known supply, and a set of destinations each with a known demand, find the minimum possible capacity for a vehicle which is to perform all the origin-to-destination transfers one at a time.

Greer, S. C., Moldover, M. R., Hocken, R., **A differential transformer as a position detector in a magnetic densimeter,** *Rev. Sci. Instrum. Notes* **45,** No. 11, 1462-1463 (Nov. 1974).

Key words: densimeter; density; differential; transformer.

We describe the use of a differential transformer to detect the position of the buoy in a magnetic densimeter, an instrument for precise measurement of fluid densities. This detector can be used in cases where the buoy is not visible and it can be assembled from commercial electronic components.

Hall, K. R., Waxman, M., **Geometrically transformed weights for least squares analyses,** *Cryogenics* **14,** No. 11, 612-614 (Nov. 1974).

Key words: implicit model; least-squares analysis; transformed weights.

The most generalized algorithm for the least-squares estimation of parameters in nonlinear, implicit models is the modified Deming approach. This technique is very complicated; however, simpler approaches for many problems lead to reasonable solutions. One widely accepted alternative is the Δ transformation of Hust and McCarty. This article offers another equally simple alternative: geometrically transformed weights.

Haynes, W. M., **Measurements of the viscosity of compressed gaseous and liquid fluorine,** *Physica* **76,** No. 1, 1-20 (Aug. 1974).

Key words: experimental; fluorine; gas; graphs; liquid; tables; torsional crystal; viscosity.

A torsionally oscillating quartz crystal has been used to make absolute measurements of the coefficient of shear viscosity for compressed fluid fluorine at temperatures from 90 to 300 K, at pressures up to 20 MPa; and for saturated liquid fluorine at temperatures from 70 to 144 K. Special features of the viscometer, necessary to provide an instrument suitable for measurements on an extremely reactive fluid such as fluorine, are described. The accuracy of the results is estimated to be of the order of 2 percent with the precision somewhat better, approximately 0.5 percent. The dependence of the viscosity on density has been investigated by representing the gaseous data along isotherms in power-series expansions. Dilute-gas viscosities were subsequently derived from this analysis. An equation has been developed that can be used to calculate the viscosity of fluorine over the range of the present measurements. Comparisons with experimental data and theoretical predictions are presented for the few measurements and calculations previously attempted for fluorine.

Hayward, E., Barber, W. C., McCarthy, J. J., **Nuclear scattering of plane-polarized photons,** *Phys. Rev. C* **10,** No. 6, 2652-2653 (Dec. 1974).

Key words: giant resonances; nuclear photon scattering; nuclear surface oscillations; plane-polarized photons.

Monochromatic 15.1 MeV plane-polarized photons have been scattered from seven additional targets having their $E1$ giant resonances near 15 MeV. They are In, Sb, Nd, Hg, Pb, Th, and U. Photons scattered through 90° were observed in the planes both parallel and perpendicular to the plane of the polarization vector. The observation of photons scattered along the polarization vector by the spherical vibrators indicates that the giant resonance is coupled to the quadrupole oscillations of the nuclear surface. The agreement with the predictions of the dynamic collective model is not particularly striking though there is little doubt that the phenomenon is qualitatively understood.

Heaton, H. T., II, Menke, J. L., Schrack, R. A., Schwartz, R. B., **Total neutron cross section of carbon from 1 keV to 15 MeV,** *Nucl. Sci. Eng.* **56,** 27-36 (1975).

Key words: carbon; neutron total cross section; pulsed neutron sources; time-of-flight.

The total neutron cross section of carbon was measured over the energy range 1 keV to 15 MeV, using the U.S. National Bureau of Standards electron linear accelerator as a pulsed neutron source. Neutron energies were measured by the time-of-flight method. The measurement accuracy is estimated to be ± 3/4 percent below 100 keV and ± 1 percent above. The carbon cross section was fit with a polynomial from 0.001 to 1.4 MeV with the following coefficients

$$\sigma = 4.757 - 3.419\,E + 1.548\,E^2 - 0.328\,E^3,$$

where σ is in barns and E in MeV. Data are compared with other results.

Hessel, M. M., Smith, E. W., Drullinger, R. E., **Transition dipole moment of Na_2 and its variation with internuclear distance,** *Phys. Rev. Lett.* **33,** No. 21, 1251-1254 (Nov. 18, 1974).

Key words: electronic dipole moment; internuclear distance; laser fluorescence; Na_2; transition moment.

The electronic transition dipole moment was determined for the transition $X^1\Sigma_g^+ \leftarrow B^1\Pi_u$ of Na_2 and was found to be $6.8 + 0.5r$ D over a range of internuclear distance r of 2.6 – 5.0 Å. Our results agree with earlier lifetime measurements and are in qualitative agreement with semiquantitative theoretical calculations, but they strongly disagree with the recent work of Callender, Gersten, Leigh, and Yang.

Hummer, D. G., Norcross, D. W., **Light ions of astrophysical interest – radiative transition probabilities for C III, N IV, O V and Ne VIII,** *Mon. Notic. Roy. Astron. Soc.* **168,** No. 2, 263-272 (1974).

Key words: atomic physics; atomic structure; oscillator strengths; radiative transition probabilities; spectra.

Multiconfiguration calculations of energy levels and bound-bound radiative transition probabilities for four astrophysically important ions of the Be isoelectronic sequence are presented. Convergence of the results with respect to the number of configurations included in the expansion is discussed. Results are presented for all ions from models with 11 and 16 configurations; including transition probabilities for 24 allowed electric dipole transitions. Some significant differences with previous calculations are obtained. The theoretical lifetimes are generally in good accord with those obtained by the beam-foil technique, and the results of other *ab initio* calculations.

Iverson, W. P., **Microbial corrosion of iron,** Chapter 19 in *Microbial Iron Metabolism,* Dr. Neilands, Ed., pp. 475-513 (Academic Press, Inc., New York, N.Y., 1974).

Key words: economics; history; iron mechanisms; microbial corrosion; prevention.

A review of the corrosion of iron by microorganisms with extensive literature survey intended as a Chapter for a 1-volume book entitled "Microbial Iron Metabolism." Includes a historical survey and economic significance of microbial corrosion, general principles of corrosion, a brief discussion of the electrochemical theory of corrosion, the thermodynamics and kinetics of corrosion, electrochemical techniques for measuring the rate of corrosion, and prevention of corrosion. The microorganisms, including fungi and bacteria involved in the corrosion of iron, are discussed extensively as well as the prevention of microbial corrosion of iron.

Jackson, J-A. A., Lias, S. G., **Primary processes in the photolysis of n-butane with 8.4 and 10.0 eV photons,** *J. Photochem.* **3,** 151-162 (1974).

Key words: alkane; electronically excited molecule; hydrogen iodide; n-butane; radical scavenging; vacuum ultraviolet photolysis.

The photolyisis of n-C_4D_{10} has been investigated with 8.4 eV and 10.0 eV photons, using HI to scavenge free radicals through the reaction: $R_D + HI \rightarrow R_DH + I$ (where R_D is a fully deuterated alkyl or alkenyl radical). From the results of such experiments, the quantum yields of the molecular and radical products are obtained over a pressure range from 3 to 47 Torr at both energies. In addition, the photolysis of $CD_3CH_2CH_2CD_3$ and $CD_3CD_2CH_2CH_3$ have been investigated in the presence of radical scavengers over a range of pressures at both energies. The results are discussed with particular emphasis on deriving the quantum yields of all the primary processes, and following changes in the quantum yields as a function of energy. Major conclusions are: (a) the quantum yield of the process ($C_4D_{10} \rightarrow C_4D_8 + D_2$) diminishes from 0.70 to 0.37 when the photon energy is increased from 8.4 to 10.0 eV; (b) the relative overall importance of direct C-C bond cleavage processes, alkane elimination processes, and D-atom elimination processes do not change significantly as a function of energy; (c) processes involving breakage of the 2, 3 C-C bond strongly predominate over processes involving the 1, 2 C-C bond at both energies, although there is a lower probability for localization of the energy in the center bond when the energy is increased.

Jacox, M. E., Milligan, D. E., **Vibrational spectrum of CO_2^- in an argon matrix,** *Chem. Phys. Lett.* **28,** No. 2, 163-168 (Sept. 15, 1974).

Key words: charge tranfer; CO_2^-; infrared spectrum; ion-molecule aggregates; matrix isolation; molecular structure.

Absorptions which appear near 1600 cm^{-1} on co-deposition at 14 K of Ar:CO_2 mixtures with an alkali metal have been assigned to ν_3 of an $M^+ \ldots CO_2^-$ ion pair, with an OCO valence angle near 130°. Molecular aggregates contribute significantly to the observed spectrum.

Jarvis, S., Jr., **Determination of velocity distributions in molecular beam frequency standards from measured resonance curves,** *Metrologia* **10,** No. 3, 87-98 (1974).

Key words: accuracy evaluation; atomic beam frequency standards; cavity phase shift; second order Doppler shift.

It is shown that the Ramsey resonance curves for most atomic beam machines can be conceived as depending on two distributions of velocity, ρ (V) and ξ (V), the second being a correction for beam width.

An analysis and computer program are described which permit one to obtain ρ, ξ and the nominal microwave power parameter from three or more measured Ramsey resonance curves at properly spaced power levels whose ratios are known. The determination from the functions (ρ, ξ) of bias errors due to second order Doppler shift, cavity phase difference, and cavity pulling is described.

The method may also be used to improve an experimentally obtained velocity distribution (i.e., one obtained through the pulse technique); to provide the proper function ξ; and to provide diagnostic checks of the measurement technique and the validity of the model chosen for the transition probability.

The method is applied to the NBS frequency standard. Error estimates indicate that it is feasible by microwave power shift measurements to evaluate the total bias error due to the above sources to within one part in 10^{13}.

Jednačak, J., Pravdić, V., Haller, W., **The electrokinetic potential of glasses in aqueous electrolyte solutions,** *J. Colloid Interface Sci.* **49,** No. 1, 16-23 (Oct. 1974).

Key words: electrokinetic potential glass; interface; liquid/solid interface; solid/liquid interface; surfaces; Zeta-potential.

Electrokinetic potentials of several glasses of well defined bulk composition in aqueous electrolyte solutions were computed from streaming current measurements. The composition of the bulk is reflected in the magnitude of the potential and in the shape of the curves relating the electrokinetic potential and the pH of the solution. No differences have been found between the crystalline and the vitreous state of silica. Addition of Al_2O_3 to the bulk results not in doping effects but rather in surface neutralization making the surface less acidic. Glasses with an appreciable amount of B_2O_3 have higher negative potentials at the same pH, and the derivatives of electrokinetic potential vs pH show them to belong to a different type of surface than vitreous or crystalline silica. Studies involving controlled pore glasses of various pore sizes have shown the importance of below-the-surface ionic penetration and/or adsorption in the pores in establishing the solid-movable liquid interfacial electrical equilibrium.

Johannesen, R. B., Peake, S. C., Schmutzler, R., **The fluorine-19 NMR spectrum of methylthiotetrafluorophosphorane,** *Z. Naturforsch. B* **29b,** 699-700 (1974).

Key words: fluorine; methylthiotetrafluorophosphorane; nuclear magnetic resonance; phosphorus.

The low-temperature ^{19}F NMR spectrum of the stereochemically nonrigid compound, CH_3SPF_4, shows three fluorine environments, one for the equatorial and two for the nonequivalent axial fluorine atoms. Each of the twelve lines of the upfield ^{19}F (axial) resonance shows further fine structure, due to coupling between ^{19}F and the protons of the CH_3S group. The center peaks of the two multiplet components reveal apparent quintet structure which, based on a computer simulation of the ^{19}F spectrum of CH_3SPF_4, is rationalized in terms of accidental overlap of two quartets.

Johnson, C. R., **Sufficient conditions for D-stability,** *J. Econ. Theory* **9,** No. 1, 53-62 (Sept. 1974).

Key words: diagonally dominant; diagonal matrix; *D*-stability; Gersgorin's theorem; Lyapunov's theorem; M-matrix; oscillatory; positive definite; principal minor; Routh-Hurwitz conditions; sign stable; sign symmetric; stability; tridiagonal.

Sufficient conditions for an n by n matrix to be D-stable are surveyed. Use is made of some transformations under which the D-stables are invariant and relations among the conditions are given. The verifiability of the thirteen conditions cited is also discussed. The lack of an effective characterization of D-stability motivates the discussion.

Kerns, D. M., **Comment on correction of errors in aerial far-field radiation-pattern determinations,** *Electron. Lett.* **7,** No. 24, 706 (Dec. 2, 1971).

Key words: antenna radiation patterns; gain measurement.

In the communication being commented on, a method is "proposed" for correcting for the effects of the measuring antenna in the determination of far-field aerial patterns from near-field measurements. This method was previously proposed in a talk in 1963 and has been substantially implemented in theoretical, experimental, and computational work. References are given.

Kline, F. J., Crannell, H., Finn, J. M., Hallowell, P. L., O'Brien, J. T., Werntz, C. W., Fivozinsky, S. P., Lightbody, J. W., Jr., Penner, S., **Search for the lowest $T=2$ state om ^{14}C by inelastic electron scattering,** *Il Nuovo Cimento* **23A,** No. 1, 137-144 (Sept. 1, 1974).

Key words: analog states; electron scattering; inelastic electron scattering; particle-hole model; resonance energy; ^{14}C.

A search for the lowest-energy $T=2$ state in ^{14}C has been attempted employing inelastic electron scattering techniques. Spectra obtained at 61 and 81 MeV incident-electron energy and 145.7° scattering angle fail to reveal significant structure at the predicted resonance energy. The implications of this result are discussed in terms of the particle-hole model and the ground-state structure of the ^{14}B analogue of this level.

Krasny, J. F., **Fabric flammability: Needs for research,** *Home Econ. Res. J.* **2,** No. 3, 160-166 (Mar. 1974).

Key words: apparel; burn injury; fabric; fire modeling; flame spread; flammability; flammability testing; garments; heat transfer; ignition.

The objective of this paper is to give a brief overview of the present status of attempts to model real life accidents involving garment fires in the laboratory, and to suggest experiments which could be carried out in the textile laboratories of home economists. The main purpose of laboratory modeling should be the definition of hazard due to the ignition and burning of garments varying in fit, fiber content, and fabric weight and construction.

Hazard from burning garments depends on the ease of ignition, rate of flame spread, heat transfer to the body, and the ease of extinguishing the garments. The literature on each of these factors is briefly reviewed, and suggestions are made for experiments which could illustrate the effects of various fabric and garment parameters on injury hazard.

Kuriyama, M., Early, J. G., Burdette, H. E., **An immobile dislocation arrangement in as-grown copper single crystals observed by x-ray topography,** *J. Appl. Crystallogr.* **7,** 535-540 (Dec. 1974).

Key words: anomalous transmission; as-grown copper crystal; crystal perfection; Czochralski growth; Lomer-Cottrell locks; sessile dislocations; x-ray topography.

X-ray diffraction topography using transmission geometry has revealed an interesting array of extremely straight and narrow long-line images in sizeable copper single crystals grown under particular growth conditions by the Czochralski technique. These images are analyzed and elucidated by a model of Lomer-Cottrell dislocations. The formation of these sessile dislocations usually aids the growth of large copper crystals of high perfection. The high degree of perfection over the entire volume of the crystals accounts for macroscopic arrangements of Lomer-Cottrell dislocations which have not previously been observed by electron microscopic techniques.

Kuyatt, C. E., DiChio, D., Natali, S. V., **Third-order asymptotic aberration coefficients of electron lenses. III. Formulas and results for the two-tube electrostatic lens,** *Rev. Sci. Instrum.* **45,** No. 10, 1275-1280 (Oct. 1974).

Key words: aberration integrals; asymptotic aberration coefficients; electron lenses; strong lenses; third-order aberration coefficients; two-tube electrostatic lens; weak lenses.

The third-order asymptotic aberration coefficients of round electrostatic electron lenses are formulated, following Hawkes, in a form independent of object and aperture positions. Six quantities are sufficient to specify completely the third-order aberration properties of electrostatic electron lenses. Equations for these six quantities are derived in the form of integrals involving derivatives of the axial potential no higher than the second. Using these equations and our previously calculated potentials and first-order trajectories we have computed the six aberrations coefficients for the two-tube electrostatic lens for voltage ratios from 1.1 to 10 000. The results are believed accurate to better than 0.2 percent.

Lafferty, W. J., Sams, R. L., **High resolution infra-red spectrum of the $2\nu_3$ band of NO_2,** *Mol. Phys.* **28,** No. 4, 861-878 (1974).

Key words: Coriolis resonance; high resolution; infrared; NO_2; spin splitting; $2\nu_3$.

The $2\nu_3$ B-type band of NO_2 has been measured, assigned and the spin splitting has been accounted for satisfactorily. Ground-state rotational constants have been obtained by fitting 6 microwave pure

rotational transitions with 119 ground-state combination differences obtained in this work. The resulting ground-state rotational constants in cm^{-1} are:

$$\mathscr{A}'' = 8{\cdot}002366 \pm 0{\cdot}000048, \qquad \Delta_{NK}'' = -(1{\cdot}943 \pm 0{\cdot}048) \times 10^{-5},$$
$$\mathscr{B}'' = 0{\cdot}433705 \pm 0{\cdot}000014, \qquad \Delta_N'' = (3{\cdot}24 \pm 0{\cdot}20) \times 10^{-7},$$
$$\mathscr{C}'' = 0{\cdot}410448 \pm 0{\cdot}000013, \qquad \delta_K'' = (1{\cdot}8 \pm 7{\cdot}2) \times 10^{-6},$$
$$\Delta_K'' = (2{\cdot}685 \pm 0{\cdot}020) \times 10^{-5}, \qquad \delta_N'' = (2{\cdot}95 \pm 0{\cdot}26) \times 10^{-8},$$
$$H_K'' = (2{\cdot}04 \pm 0{\cdot}95) \times 10^{-6},$$

where uncertainties are 3σ. Upper-state constants have also been obtained. Anomalous line intensities are observed throughout the band. The most striking of these anomalies is the observation of very strong $^{P}P_K$ series even for moderately high K values while no $^{P}P_K$ or $^{R}P_K$ lines have been observed.

Lamaze, G. P., Carlson, A. D., Meier, M. M., **A new measurement of the $^{10}B(n,\alpha)^7Li$ branching ratio,** *Nucl. Sci. Eng.* **56,** Tech. Note, 94-96 (1975).

Key words: $^{10}B(n,\alpha)^7Li$ reaction; branching ratio; gas proportional counter; neutrons; nuclear physics; T(p,n) neutrons.

To resolve a discrepancy in determinations of the $^{10}B(n,\alpha)^7Li$ branching ratio, a new measurement has been made at the National Bureau of Standards (NBS). The measurement was made with a $^{10}BF_3$ gas proportional counter and monoenergetic 790-keV neutrons obtained at the NBS 3-MV Van de Graaff laboratory. A branching ratio of 0.66 ± 0.03 was obtained. This determination agrees with the measurements of Petree et al. and Davis et al.

Lawless, W. N., Radebaugh, R., Siegwarth, J. D., **Improvements on "low-temperature dielectric bolometer,"** *J. Opt. Soc. Amer.* **64,** No. 6, 820-822 (June 1974).

Key words: bolometer; cryogenics; dielectric; glass-ceramic; optics.

This paper corrects a definitional error in the previous paper on this topic and reports a considerably better dielectric material for this type of detector (i.e., $d\ln\epsilon/dT$ values as large as 30% K^{-1} in the range 0.3 to 10 K). Computed responsivity (times the square root of the detector area) based on this material varies from 6×10^6 to 2×10^4 V · W^{-1} · cm for reservoir temperatures between 0.3 and 10 K. The corresponding variation of the detectivity is from 2×10^{14} to 1×10^{11} cm · W^{-1} · $Hz^{1/2}$.

Lawton, R. A., **Autocorrelation and power measurement with pyroelectric and dielectric bolometers,** *IEEE Trans. Instrum. Meas.* **IM-22,** No. 4, 299-306 (Dec. 1973).

Key words: autocorrelation; detector; pulse; pyroelectric.

A pulse comparison technique is described which yields the autocorrelation function and the power spectrum of a repetitive time-domain waveform. The autocorrelation function is realized with a sliding short in a coaxial transmission line to provide time delay; a pyroelectric bolometer to provide multiplication through a square law voltage response; and a capacitor to provide integration. Problems of realization of a perfect time delay and integration limitations are considered, and it is found that noise fluctuations yield the main time resolution limitation that is equivalent to 8 ps for 15-V pulses and a 50-s integration time. The pyroelectric voltage-sensing bolometer is then compared to a pyroelectric capacitance sensing bolometer. It is shown that the capacitance sensing bolometer can handle much longer pulse durations than the voltage sensing bolometer. It is also demonstrated that the sensitivities of the two techniques are equivalent in a typical case at a capacitance sensing bolometer bridge voltage of 3 V. Measurement results of the autocorrelation function and power spectrum, using a voltage sensing pyroelectric bolometer, are given for a nominal 15-V, 500-ps time duration, whose baseband pulses have a 100-pps (pulses per second) repetition rate.

Lawton, R. A., Nahman, N. S., **Pyroelectric detector application to baseband pulse measurements,** *Electron. Lett.* **8,** No. 12, 318-320 (June 15, 1972).

Key words: detector circuits; power measurement; pulse circuit; pyroelectricity.

A square-law detector for picosecond baseband pulse comparison techniques has been realised using the pyroelectric effect. By using thin-film techniques, a broadband signal transfer to the detector was obtained. The theoretical principles of the detector and some applications are briefly discussed. Attention is given to measurements of pulse-energy content, pulse autocorrelation function and pulse cross-correlation function.

Little, W. E., **Automated computer controlled measurements,** (Proc. 1974 Conf. on Precision Electromagnetic Measurements, London, England, July 1-5, 1974), Abstract in *CPEM Digest* No. 113, 331-332 (Institution of Electrical Engineers, London, England, 1974).

Key words: automated measurements; computer; concepts; reliability; state-of-the-art; survey.

The primary intent of this paper is to give a state-of-the-art survey of automated-computer controlled measurements in the context of what has been done in the past that has direct bearing on the present work and the directions that the near future work will take.

The paper will cover some of the evolution of computer controlled measurement systems including concepts utilized in the system designs. The discussion will start with the concept of utilizing the computer to handle large amounts of data from *traditional* systems to give more data handling reliability and then go into the concepts of using the computer not only to collect the data but to control the actual measurement instruments to allow for even more reliability and in some cases improved measurement accuracy. From there, it will go into the concept of using the compuer not only to control the instruments and collect the data but to actually model the system. Here, numerical data which represents system parameters is stored in the computer memory and later utilized to correct the measurement data so that the system will appear nearly perfect and an improvement in measurement accuracy is achieved.

Finally, a summary of the state-of-the-art in automated computer controlled measurement equipments and techniques will be given. It will be given in the context of measurement accuracy achieved, measurement efficiency, reliability, and measurement concepts employed in the system design.

Mann, D. B., Dean, J. W., Brennan, J. A., Kneebone, C. H., **Cryogenic flow measurement—positive displacement volumetric flowmeters,** (Proc. 1st Symp. on Flow, Its Measurement and Control in Science and Industry, Pittsburgh, Pa., May 9-14, 1971), Paper in *Flow, Its Measurement and Control in Science and Industry,* Part 2, pp. 381-386 (Instrument Society of America, Pittsburgh, Pa., 1974).

Key words: cryogenic; flow; flowmeters; liquid nitrogen; measured; positive displacement.

The National Bureau of Standards and the Compressed Gas Association (CGA) have jointly sponsored a research program on cryogenic flow measurement. A cryogenic flow research facility was constructed and was first used to evaluate commercially available cryogenic flowmeters operating on a positive displacement principle. The operation and the accuracy of the flow facility is briefly described. The performance of the flowmeters on liquid nitrogen is summarized by reporting the precision and bias of the meters before and after an 80-h stability test and by defining the existence of temperature, flow rate, subcooling, and time order (wear) dependencies. Meters were evaluated with flow rates ranging from 0.00126 to 0.0063 m^3/s (20 to 100 gpm), pressures ranging from 0.34 to 0.69 MN/m^2 (50 to 100 psig), and with temperatures ranging from 72 to 90 K.

Massey, R. G., Druckenbrod, W. F., **Terms and definitions for Police Patrol Cars,** *LESP-RPT-0401.00,* 18 pages (U.S. Department of Justice, Law Enforcement Assistance Administration, National Institute of Law Enforcement and Criminal Justice, Washington, D.C., May 1974).

Key words: patrol car definitions; patrol car functions; patrol car systems; patrol car terms.

This document contains the definitions of terms related to four-wheeled, on-road vehicles used in law enforcement. The terms and definitions have been selected on the basis of usefulness to those responsible for the selection, procurement, and use of those vehicles.

McKinney, J. E., **PVT behavior of polymeric liquid-glass systems,** *Proc. 30th National Conf. on Fluid Power, Philadelphia, Pa., Nov. 12-14, 1974,* **XXVIII,** 393-411 (1974).

Key words: density; entropy; free volume; glasses; glass transition; liquid; polymer; poly(vinyl acetate); PVT; relaxation; viscosity.

Techniques and procedures are described which are appropriate to obtain proper PVT data on liquid-glass systems. As a result of the non-equilibrium character of glasses (resulting from their very long viscoelastic relaxation times), the thermodynamic history of glass formation has considerable influence on structure and corresponding properties. Accordingly, highly systematic experimental procedures are necessary to obtain meaningful data to properly specify the properties of a liquid-glass system.

Most of the data presented here pertain to poly(vinyl acetate), and amorphous polymer, for which the thermodynamic response is considered to be in a qualitative sense typical of the liquid-glass systems. This polymer is particularly convenient to study because of its glass transition near room temperature. Through the appropriate choice of histories, two types of glass transition temperatures (with their corresponding PVT surfaces) may be observed and defined. One of these may be considered to be a thermodynamic transition applicable to thermodynamically reversible systems, the other, a kinematic transition for which dT/dP approximates the isoviscous state. The latter is therefore of interest in application to fluid transfer analysis at high pressures. In general, the values of dT/dP of the former exceed those of the latter by roughly a factor of two. The thermodynamic data describing these two transitions make possible the proper evaluation of the Ehrenfest Relations for liquid-glass systems.

The use of high pressure to "permanently" densify glasses during formation is described. This procedure results in commensurately higher refractive indices which have applications in optical technology.

The results from the more recent experiments of this type reveal certain contradictions with present phenomenological and molecular theories. A few of the more promising examples are given along with the types of modifications necessary for more accurate prediction of thermodynamic and kinematic properties.

McLaughlin, W. L., **Solid-phase chemical dosimeters,** (Proc. Int. Conf. on Sterilization by Ionizing Radiation, Vienna, Austria, April 1-4, 1974), Paper in *Sterilization by Ionizing Radiation,* E. R. L. Gaughran and A. J. Goudie, Eds., pp. 219-252 (Multiscience Publication Ltd., Montreal, Quebec, Canada, 1974).

Key words: dose distribution; dosimetry; dyes; electron beams; gamma rays; glasses; plastics; radiation chemistry; radiation sterilization; solid-state detectors; spectrophotometry.

The radiation chemistry and response characteristics of some solid-phase chemical dosimeters (plastics, dyed plastics, and glasses) are reviewed. The analysis used for dosimetry is mainly spectrophotometry in the ultraviolet and visible spectrum. Systems having a reproducible response and a stable optical absorbance are selected from as many as 28 candidate systems, some of those showing promise for radiation sterilization applications being: polymethyl methacrylate, dyed polymethyl methacrylate, polycarbonate, tetrazolium salt in polyvinyl alcohol, dyed polychlorostyrene, and dyed polyamide. Major sources of dosimetric error, such as temperature and dose rate dependence instability, non-uniformities, and batch differences, are examined.

Melmed, A. J., Carroll, J. J., Meclewski, R., **Dependence of work function on coverage for aluminum/tungsten in the field electron microscope,** *Surface Sci.* **45,** 649-656 (1974).

Key words: aluminum; field emission; tungsten; work function.

Aluminum adsorption on tungsten has been investigated by field electron microscope techniques. Changes in average work function and work functions of the (001) plane and (111) region were determined as a function of aluminum deposition. The average work function exhibits a minimum of about (4.11 ± 0.04) eV (relative to an assumed value of 4.50 eV for the tungsten substrate) and reaches a value of (4.21 ± 0.04) eV for thick deposits. The (001) plane and (111) region exhibit complicated work function dependences on aluminum coverage. Some qualitative observations of aluminum on tungsten surface diffusion are also reported.

Mies, F. H., **Calculated vibrational transition probabilities of OH($X^2\Pi$),** *J. Mol. Spectrosc.* **53,** 150-188 (1974).

Key words: Einstein coefficients; line strengths; Meinel bands; molecular spectra; OH; radiative lifetimes; spin uncoupling; vibration-rotation interaction; vibrational transitions.

The theoretically derived dipole moment function of OH($X^2\Pi$) obtained by Stevens Das, Wahl, Neumann, and Krauss is used to calculate the absolute intensities of the vibrational-rotational transitions of the OH Meinel bands. The calculations take full account of the spin uncoupling and vibration-rotation coupling which markedly influence the radiative transition probabilities. The effect of lambda-doubling on the vibrational transitions is analyzed and generally found to be negligible. Results are tabulated for $\Delta v = v' - v''$ ranging from the fundamental transitions $\Delta v = 1$ to the $\Delta v = 5$ overtone, for $v' = 1$-9 and $J' = 0.5$-15.5. A comparison is made with available data, and various features of the OH spectrum are examined that are of aeronomical and experimental interest. Thermally averaged emission rates are presented for $\Delta v = 1$-5, and the validity of the rotational temperatures commonly derived from experimental intensity distributions is questioned.

Mihalas, D., Hummer, D. G., **Theory of extended stellar atmospheres. I. Computational method and first results for static spherical models,** *Astrophys. J. Suppl. Ser.* **28,** No. 265, 343-372 (Oct. 1974).

Key words: astrophysics; early-type stars; radiative transfer; spectral line formation; stellar atmospheres.

A method is presented that makes possible, for the first time, the calculation of extended spherical non-LTE model stellar atmospheres in hydrostatic and radiative equilibrium. This method is a generalization of the complete-linearization technique of Auer and Mihalas. Models have been obtained for a star with $m = 60 m_\odot$, $L = 1.25 \times 10^6$ $L_\odot$, and $R = 24 R_\odot$, whose atmosphere is characterized by an effective temperature $T_{eff} = 39{,}500$ K and a surface gravity $\log g_6 = 3.45$, i.e., with a spectral type near O6. These models are differentiated by the magnitude and radial dependence of a radiation force multiplier γ that is inserted into the equation of hydrostatic equilibrium to simulate the effect of radiation force on opacity sources which have not been included explicitly in the calculation. Models have been obtained very close to the limit at which the radiation force and gravity balance; as this condition is approached, the atmospheres become more and more extended. Only hydrogen and helium ($Y = 0.1$) have been included, and six hydrogen lines have been treated explicitly. Although these models show only modest extension, they predict Lα in emission, the lower Balmer lines in absorption, the Balmer jump in absorption, and an infrared excess and ultraviolet deficiency relative to the visual. Continuous energy distributions and the profiles and

equivalent widths of Lα, Hα, Hβ, and Hγ are tabulated. The models predict an intrinsic reddening of the colors of extended envelopes relative to plane-parallel atmospheres. A procedure for the extraction of the intrinsic colors of luminous stars from heavily reddened observations is described.

Molino, J. A., **Measuring human aversion to sound without verbal descriptors,** *Percept. Psychophys.* **16,** No. 2, 303-308 (Oct. 1974).

Key words: aversion for sound; avoidance; differential reinforcement of high rate; escape; high school students; key press; pure tones; second order schedules.

High school students tapped rapidly on a telegraph key to reduce the intensity of a continuous acoustic stimulus presented through earphones. Failure to respond resulted in an intensity increase of 1 dB every 4 sec. In Experiment 1, a group of 19 students responded to three pure tones (125, 1,000, and 8,000 Hz) and a white noise. The different asymptotic levels observed after 4 min were taken as a measure of equal-aversion levels for the stimuli. In Experiment 2, the effect of the starting intensity level (45, 70, and 90 dB SPL) was determined for a 1,000-Hz tone. Differences in the asymptotic intensity levels observed after 6 min were not significant. In Experiment 3, no significant effect was found upon varying the number of responses required to produce a 1-dB intensity decrement in a 1,000-Hz tone. Together, the experiments demonstrated the feasibility of determining equal-aversion levels for sounds.

Molino, J. A., Zerdy, G. A., Frome, F. S., **Toward a more musical foghorn,** *Hum. Factors.* **16,** No. 6, 567-575 (Dec. 1974).

Key words: acoustic navigation aids; applied psychoacoustics; applied psychology; aversiveness; foghorns; preference; pure tones.

Ten college students gave preference judgments for 4 pure tones (120, 300, 500, and 835 Hz) and 11 tone composites constructed from combinations of the pure tones. Equal aversion (tolerance) levels were also measured for the four pure tones and for five of the composites. Sensation-level measures were employed to express aversion thresholds in order to take account of the differential sensitivity of the human ear at different frequencies. Certain operational conclusions were suggested for the design of acoustic navigation aids. The higher frequency pure tones and composites were generally more preferred, and were also tolerated at higher sensation levels. The 120-Hz pure tone was a highly non-preferred signal. The presence of a 120-Hz component in any composite lowered both the preference value and the maintained sensation level. In the case of the moderately preferred 500-Hz pure tone, adding other more-preferred, pure-tone components increased the preference for the signal.

Ogburn, F., **Methods of testing,** Chapter 30 in *Modern Electroplating*, 3d Edition, pp. 673-709 (July 1974).

Key words: coatings; electroplated coatings; metal coatings; test methods for metal coatings; testing electrodeposits.

A brief description and evaluation is given of each of the methods used to test electroplated coatings for thickness, corrosion resistance, porosity, internal stress, ductility, hardness, and solderability.

Pella, P. A., **A discussion of a performance standard for evidential breath alcohol instruments,** (Proc. 1974 Carnahan and International Crime Countermeasures Conf., Lexington, Ky., April 16-19, 1974), Paper in *Proceedings 1974 Carnahan and International Crime Countermeasures Conference, UKY Bull.* **105,** 98-101 (1974).

Key words: breath alcohol; instruments; performance standard; specifications; test procedures.

The variety of commercially available breath alcohol instruments for use in law enforcement programs has been increasing steadily. As a result of these developments, officials involved in countermeasures programs are requesting guidance concerning their reliability. The need for accuracy of the measured values obtained with these instruments has been emphasized in the courts. Therefore, it is essential that criteria be established to provide a basis for the selection of acceptable breath-testing equipment. In response to this need, the National Highway Traffic Safety Administration (NHTSA) has sponsored the development of a performance standard [1]. Instruments which are in compliance with this standard will be placed on a qualified products list. Funds used to purchase such equipment can then be utilized more effectively. Performance standards are presently being developed by the National Bureau of Standards for NHTSA. The first of these standards, described in detail in reference 1, applies to evidential breath alcohol instruments. Some selected highlights from this standard will be the subject of this presentation.

Pella, P. A., **Mössbauer spectrometry,** Chapter 26 in *Systematic Materials Analysis*, J. H. Richardson and R. V. Peterson, Eds., **III,** 241-267 (Academic Press, New York, N.Y., 1974).

Key words: materials characterization; Mössbauer spectrometry; nuclear resonance.

This book chapter entitled "Mössbauer Spectrometry," which appears in *Systematic Materials Analysis*, Vol. III, pp. 241-267, J. H. Richardson and R. V. Peterson, Eds., Academic Press, Inc., New York, 1974, is essentially tutorial. This chapter describes the theory and practice of this technique in a manner oriented toward the student on the graduate level or analyst who finds himself with a materials characterization problem. This chapter draws heavily on already published material, and written, I hope, with the intention of conveying to the reader what information can be obtained by this technique. The chapter includes theory, instrumentation, sample preparation, and gives examples of application in the areas of mineralogy, metallurgy, magnetic properties, chemical structure and bonding, solid-state studies, and data handling.

Phelan, R. J., Jr., Peterson, R. L., Hamilton, C. A., Day, G. W., **The polarization of PVF and PVF_2 pyroelectrics,** *Ferroelectrics* **7,** 375-377 (1974).

Key words: polyvinylfluoride; polyvinylidene fluoride; pyroelectrics.

Through detailed investigations of the modulation frequency response of pyroelectric detectors, nonuniform polarizations have been shown to exist in polyvinylfluoride and polyvinylidene fluoride plastics. The nonuniform polarization is also confirmed by measurements using multilayer structures. The direction and magnitude of the gradients in polarization are dependent on the magnitude and polarity of the poling voltage. The gradients in the polarization for PVF and PVF_2 are opposite in direction. Using structures that allow for poling to 2×10^6 V/cm uniform polarizations, the highest responsivities and improved frequency responses were obtained.

Radebaugh, R., Siegwarth, J. D., **Heat transfer between fine copper powders and dilute ^{3}He in superfluid ^{4}He,** (Proc. 13th Int. Conf. on Low Temperature Physics, Boulder, Colo., Aug. 21-25, 1972), Paper in *Low Temperature Physics LT 13*, K. D. Timmerhaus, W. J. O'Sullivan, and E. F. Hammel, Eds., **1**, 401-405 (Plenum Press, New York, N.Y., 1974).

Key words: copper; heat transfer; helium 3-helium 4; Kapitza resistance; phonon-electron interaction; phonon-quasiparticle interaction; powder; sintering.

The recently measured value of the phonon-electron thermal resistance is too low to have been seen in previous measurements of the Kapitza resistance of high surface area materials below 0.1 K. We report here measurements of the thermal resistance between dilute ^{3}He liquid and copper powder of characteristic spherical diameter, based on adsorption studies, of 1.6 μm. With this fine powder we should expect to see, below about 50 mK, the phonon-electron thermal re-

sistance and the phonon-^{3}He quasiparticle thermal resistance. However, measurements down to 15 mK on three different samples of this powder show no signs of these additional resistances. The thermal resistance-surface area product has the typical Kapitza resistance behavior of $R\sigma T^3 \approx$ constant for temperatures below that where the thermal resistance of the liquid in the sponge dominates. The value for the constant is in fair agreement with the value 280 cm^{2}K^4/W that we find for annealed bulk OFHC copper in dilute ^{3}He.

Raveché, H. J., Mountain, R. D., Streett, W. B., **Freezing and melting properties of the Lennard-Jones system,** *J. Chem. Phys.* **61,** No. 5, 1970-1984 (Sept. 1, 1974).

Key words: equation of state; freezing; freezing criteria; melting; molecular correlation functions; phase transitions.

Using Monte Carlo simulations, we investigate average molecular arrangements that occur with the fluid-solid transition in a classical Lennard-Jones system. The crystalline order of the solid phase is explicitly shown by the angularly averaged molecular correlation functions which, in the solid, exhibit a behavior not observed in the fluid. The pair and triplet correlation functions delineate the crystalline pattern of the ordered phase out to internuclear separations of many nearest-neighbor distances. A molecular criterion for freezing is reported which claims a proportionality between the values of the pair correlation function in the fluid at the positions of the first and second nearest neighbors. The general behavior of the triplet correlation function in the fluid phase is interpreted. We also compare predictions for melting pressures and the densities of the coexisting fluid and solid phases.

Reed, R. P., Schramm, R. E., **Relationship between stacking-fault energy and x-ray measurements of stacking-fault probability and microstrain,** *J. Appl. Phys.* **45,** No. 11, 4705-4711 (Nov. 1974).

Key words: deformation; dislocations; face-centered cubic metals; faults; Fourier analysis; review; stacking fault energy; x-ray diffraction.

Stacking-fault energies can be determined by measuring the positions and profiles of x-ray diffraction lines. Use of this method has been hampered by the uncertainty of the relationship between stacking-fault energy and the ratio of microstrain to stacking-fault probability. Microstrains and stacking-fault probabilities have been determined for five fcc metals by x-ray diffraction line profile analysis. For these metals, Ag, Au, Cu, Al, and Ni, stacking-fault energies have been estimated from a comprehensive updated review of the experimental literature. A linear correlation does exist between γ and $\langle \epsilon_{50}^2 \rangle_{111}/\alpha$ and thus, the x-ray technique can be applied more confidently. The possible role of elastic anisotropy is also considered.

Ruegg, F. W., **Expansion factors for two variable area flow meters,** *J. Eng. Ind. Trans. ASME Papers No. 73-WA/FM-2,* **96,** No. 4, 1347-1353 (Nov. 1974).

Key words: coefficients of discharge; expansion factor; flow coefficients; flowmeter; fluid meter coefficients; rotameter; variable area meter.

Data acquired in the years 1958 to 1960 at the Naval Ship Engineering Center under sponsorship of the American Society of Mechanical Engineers are used to derive semiempirical equations for the performance of two variable area meters with both liquid and gas flow. As the measurements are put to a useage for which they were not intended, the data treatment is considered illustrative of the application of a flow equation derived by an analysis based upon a force and momentum balance. The hydraulic flow coefficient is expressed in terms of a function of (a) pressure drop divided by float weight and of (b) a dimensionless length ratio β for float position. Density ratio is used to modify the function of β to derive the expansion factor Y for gas flow as suggested by the analysis. Reasonable agreement between measured and derived values of Y is demonstrated, and approximate measures of the velocity profiles in the meter are derived from the correlation equations. One set of air tests at one float position in which the viscous influence number N was changed from 500,000 to 783,000 indicated (within this range) a possible insensitivity of the derived function of β to change of N.

Ruff, A. W., Fraker, A. C., **Investigation of the anisotropic anodic polarization behavior of titanium,** *Corrosion* **30,** No. 7, 259-264 (July 1974).

Key words: corrosion; passivation; single crystals; sulfuric acid; titanium.

Anodic polarization measurements have been made potentiostatically on single crystal and polycrystal titanium in 1N H_2SO_4 at 23 C (73 F). Three low index surfaces, (0001), (1120), and (1010) were studied together with polycrystalline rolled sheet material. A strong influence of crystallographic orientation on the anodic current densities was found in both the active and the passive regions. The most active surface was (1120), the least active (0001). The most passive surface was also (0001), unless the specimen had been in a cathodic region, whereupon that orientation became the most reactive. That effect and others that are associated with titanium hydride formation are discussed. The effect on the reactivity of the polycrystalline surface due to preferred orientation texture is mentioned.

Runyan, C. C., Moulder, J. C., Clark, A. F., **Time-resolved spectra of bulk titanium combustion,** *Combust. Flame Brief Communication* **23,** No. 1, 129-133 (Aug. 1974).

Key words: combustion; laser ignition; spectra (visible); titanium.

The combustion of titanium specimens is supported by a laser in gaseous oxygen. Utilizing a high-speed mechanical shutter driven by a time-delay circuit, the presence of titanium and its oxides is monitored above the surface of the burning Ti metal as a function of time. Spectra are taken with a grating spectrometer and are compared for various stages of the combustion process. The stages are defined by the shape of the total emitted intensity curve. Discrete spectra of titanium and titanium monoxide are seen in emission but disappear as the combustion progresses. The results are correlated with metallographic and x-ray analyses of quenched specimens.

Sanchez, I. C., Peterlin, A., Eby, R. K., McCrackin, F. L., **Theory of polymer crystal thickening during annealing,** *J. Appl. Phys.* **45,** No. 10, 4216-4219 (Oct. 1974).

Key words: annealing; crystalline polymers; material transport; thickening; volume change.

A previous theory of thickening has been extended to encompass the possible dependence of cooperative chain transport on lamella thickness and crystallinity changes during annealing. These have marked effects on the thickening rate leading to changes in slope and departures from straight-line behavior of the plots of lamella thickness versus the logarithm of time. The resulting curves bear a resemblance to many experimental ones in the literature. Also brought out by the analysis is the important fact that the volumes of the coherently thickening domains are not known from experiment.

Schneider, S. J., McDaniel, C., **Problems in accurate temperature measurement: The melting point of Y_2O_3,** *Can. Met. Quart.* **13,** No. 2, 365-368 (1974).

Key words: IPTS-68; melting point; secondary temperature standards; temperature scales; Y_2O_3.

Modern day pyrometry permits the measurement of temperature with maximum uncertainties ranging between about 0.1 °C at 1064 °C (gold point) and 2 °C at 3525 °C. These uncertainties refer to the realization of the International Practical Temperature Scale (IPTS) and represent the level of accuracy a temperature per se can be determined under optimized conditions. Unfortunately, the measurement of a material property as a function of temperature imposes ex-

perimental constraints which seriously degrade the inherent accuracy of the temperature measurement system, often to unknown levels. Consequently, in situ temperature calibrations are required which must employ the use of a well characterized reference material compatible with the environment of the experiment. Suitable secondary temperature reference standards are not generally available and this lack is being addressed by the High Temperature Commission (IUPAC) through its current melting point program on Y_2O_3 and formerly by its efforts on Al_2O_3.

The determination of fixed points presents many experimental difficulties relevant to a wide range of physico-chemical measurements and can serve as an illustrative example of the high temperature problems which may be encountered. Through a description of the experimental determination of the melting point of Y_2O_3 (2422 °C) this paper delineates major problem areas and includes discussions on IPTS, temperature measurement techniques and calibration and materials behaviour and compatibility.

Sengers, J. M. H. L., Greer, W. L., Sengers, J. V., **Scaled parametric equation of state for oxygen in the critical region,** (Proc. 1973 Cryogenic Engineering Conf., Atlanta, Ga., Aug. 8-10, 1973), Paper in *Advances in Cryogenic Engineering*, K. D. Timmerhaus, Ed., **19**, 358-364 (Plenum Press, New York, N.Y., 1974).

Key words: critical coefficients; critical exponents; critical region; density profile; dielectric constant; linear model; oxygen; scaling laws; statistical analysis.

A method is described for fitting critical-region equation-of-state data with a particular scaled equation-of-state, the so-called Linear Model. The method has been applied to the density profiles observed by Weber in the critical region of oxygen. The Linear Model is shown to fit these data well, except for a small region on the critical isochore close to T_c. The optimized critical exponents, however, do not agree very well with those from Weber's power-law analysis. Some sets of equation-of-state parameters are presented as starting points for further thermodynamic calculations on oxygen.

Shine, R. A., Linsky, J. L., **A facular model based on the wings of the Ca II lines,** *Solar Phys.* **37**, 145-150 (1974).

Key words: sun-faculae; sun-photospheric models; Van der Waals line broadening.

We develop a relatively simple procedure for deriving models of upper photospheric regions based on the damping wings of the Ca II resonance and infrared triplet lines. The procedure is used to derive a facular model but can also be applied to late-type stars. We compare our model to that of Chapman.

Smith, R. L., Case, W. E., Rasmussen, A. L., Russell, T. W., West, E. D., **A calorimeter for high power CW lasers,** (Proc. Conf. on Precision Electromagnetic Measurements, Boulder, Colo., June 26-29, 1972), Paper in *CPEM Digest, pp. 138-139 (1972).*

Key words: laser; laser calorimetry; laser energy measurements; laser power measurements.

A calorimeter was built to measure the total energy emitted by a CW laser whose output wavelength is in the region from 1 μm to 11 μm. This instrument can measure energies from 10^5 to approximately 10^7 joules with about 5 percent uncertainty and it can measure energies down to about 10^4 joules with a larger uncertainty. The calibration factor for this device is approximately 2.26×10^6 joules/volt, where one volt corresponds to a temperature interval of approximately 12 °C. The laser power that can be accommodated by this instrument ranges from about 500 watts to 100,000 watts. The maximum beam diameter it will accept is 10 cm.

Streett, W. B., Raveché, H. J., Mountain, R. D., **Monte Carlo studies of the fluid-solid phase transition in the Lennard-Jones system,** *J. Chem. Phys.* **61**, No. 5, 1960-1969 (Sept. 1, 1974).

Key words: fluid-solid phase transition; Lennard-Jones model; melting and freezing densities; Monte Carlo simulation; symmetry change; van der Waals isotherm.

Monte Carlo calculations for 108- and 256-particle Lennard-Jones systems have been carried out at 140 temperature-density points in the vicinity of the fluid-solid phase transition. Several types of initial configurations have been used, including fcc lattice arrays, disordered arrays, and combinations of lattice and disordered arrays. The results of runs at high densities show that for small periodic systems the calculations are dependent on the initial configuration and that such systems can exist in many different metastable states from which minimum energy states are not accessible in runs of the order of 10^6 to 10^7 configurations. In the vicinity of the smallest density at which the fcc lattice is stable, the calculated pressure-volume curve exhibits many of the features of a "van der Waals loop"; however, because a single phase is thermodynamically unstable over part of this region, the loop cannot be completely resolved through machine calculations. The use of the van der Waals loop to estimate the melting parameters for the Lennard-Jones system leads to fluid and solid densities 3 to 4 percent lower than those calculated by the indirect method of Hansen and Verlet.

Sugar, J., Kaufman, V., **Spectra and energy levels of three- and four-times ionized hafnium (Hf IV and Hf V),** *J. Opt. Soc. Amer.* **64**, No. 12, 1656-1664 (Dec. 1974).

Key words: energy levels; hafnium; ionization energies; Slater parameters.

The spectra of hafnium produced by a sliding-spark discharge operating at peak currents of 6 to 1200 A were photographed in the spectral range of 400 to 2100 Å. Sixty-three lines of Hf IV were measured in the limited range of ~ 500-900 Å, of which 43 were classified. New levels in the $4f^{14}nl$ doublet term system of Hf IV were found for $nl = 6f$, $7p$, and $8s$. In addition, the resonance transition array $4f^{14}5d$-$4f^{13}5d^2$ was interpreted. In Hf V 216 lines were observed. With these data, all levels of the configurations $4f^{13}nl$ for $nl = 6s$, $7s$, $6p$, $5d$, and $6d$ were found except for two levels of $4f^{13}6d$. Theoretical interpretations are given of all of the above configurations. Values for the ionization energies of both species were derived.

Sugar, J., Spector, N., **Spectrum and energy levels of doubly ionized europium (Eu III),** *J. Opt. Soc. Amer.* **64**, No. 11, 1484-1497 (Nov. 1974).

Key words: energy; energy levels; europium; ionization; spectrum.

The spectrum of Eu III obtained with a 6 A sliding-spark discharge has been measured from 2000 Å to 9000 Å. Of the 890 spectral lines observed, one-third are classified in an energy-level scheme consisting of 104 excited levels. These belong to the $4f^7$ configuration and to the $4f^6(^7F)5d$, $4f^6(^7F)6s$, and $4f^6(^7F)6p$ subconfigurations. Except for $4f^7$, calculations of these configurations with least-squares-adjusted parameters were carried out. A reasonably suitable truncation for the energy matrices of each configuration was found.

Van Brunt, R. J., Kieffer, L. J., **Angular distribution of O^- from dissociative electron attachment to NO,** *Phys. Rev. A* **10**, No. 5, 1633-1637 (Nov. 1974).

Key words: dissociation; electron; ionization; molecular oxygen.

The electron energy dependence of the angular distribution of O^- produced by dissociative electron attachment to NO has been measured in the energy range 8.0-11.0 eV. The distributions are observed to be anisotropic and of a form that is nearly $\sin^2\theta$ at all energies. Deviations from a $\sin^2\theta$ dependence are discussed in terms of the relative contributions of different partial waves to the differential cross section. The results indicate that the final repulsive negative-ion resonances involved must be either Σ or Δ states.

Wacker, P. F., **Antenna measurements at the National Bureau of Standards near-field and extrapolation techniques,**

(Abstract only), (Proc. 5th Colloquium on Microwave Communication, Budapest, Hungary, June 24-30, 1974), pp. ME-113–ME-114 (Academy of Sciences, Budapest, Hungary, 1974).

Key words: antennas; extrapolation; measurements; near-field.

Near-field antenna measurements can yield especially accurate patterns and gain values, since they are subject to the precise control of a closely-coupled laboratory system and are free of errors due to ground reflections and grazing reflections from the walls of an "anechoic" chamber. Moreover, for a planar, circular-cylindrical, or spherical scanning surface, the far-field pattern may be computed from near-field data without significant approximation, provided the probe pattern is known, the medium is homogeneous and isotropic, and the medium, probe, and antenna or array are electrically linear. (The full complex-vector transmitting, receiving, and scattering properties of the antenna and probe are expressed by means of a generalization of an n-port scattering matrix, each mode (e.g., plane wave of a given direction and polarization) being considered as a port. Data processing consists primarily of a Fast Fourier Transform, followed in the spherical case by a matrix multiplication.) If the antenna is mounted on a conventional rotator, "spherical scanning" requires no probe transport.

For fixed orientations of two antennas, exact functional forms for the received signal as a function of distance permit correction for multiple-reflection and proximity effects and so yield accurate far-field values from measurements made on small ranges.

Recent NBS developments and measurements with these techniques will be described.

Wacker, P. F., **Near-field antenna measurements using a spherical scan: Efficient data reduction with probe correction,** (Proc. 1974 Conf. on Precision Electromagnetic Measurements, London, England, July 1-5, 1974), Paper in *CPEM Digest*, No. 113, 286-288 (Institution of Electrical Engineers, London, England, 1974).

Key words: antenna measurements; data reduction; near field; probe correction; probe design; spherical scan.

A new data reduction scheme makes practical the determination of patterns of electrically large antennas from near-field spherical scans.

Weissler, P. G., Kobal, M. T., **Noise of police firearms,** *J. Acoust. Soc. Amer.* **56,** No. 5, 1515-1522 (Nov. 1974).

Key words: damage risk criteria for impulse noise; gunfire noise; noise-induced hearing damage; noise of police firearms.

In an effort to provide guidelines for law enforcement personnel to protect their hearing, the peak pressure level and signal duration (*A* and *B* duration) of eight popular firearms were measured and compared with the requirements of OSHA (1970), CHABA DRC (1968), and EPA levels (1974). Small condenser microphones and a storage oscilloscope were used to record the blast wave signatures from a 9-mm automatic, 0.357-cal. Magnum revolver, 0.41-cal. Magnum revolver, 0.22-cal. revolver, 0.45-cal. automatic, 0.44-cal. Magnum revolver, 12-gauge shotgun, and 0.22-cal. rifle. Measurements were made at the ear of the person shooting and at the approximate position of a neighbor at a firing range. Some measurements were also made at a practice firing range. A portable tape recorder was found useful for recording gun signals and measuring *B* durations. The peak pressure levels of the signatures of all the firearms tested exceed the OSHA maximum of 140 dB. It was found that in an anechoic environment the noise from five of the handguns exceeded the CHABA DRC (1968), while the noise from all of the firearms tested, except the 0.22-cal. rifle, exceeded the EPA levels (1974). At a sound-insulated firing range, the noise from all the firearms tested, except the 0.22-cal. rifle, exceeded the CHABA DRC (1968), while all the firearms tested exceeded the EPA levels (1974).

Wexler, A., **Humidity measurement system–A micro study,** *Nat. Conf. Stand. Lab. Newsletter* **14,** No. 2, 38-41 (Oct. 1974).

Key words: humidity measurement; moisture; standard; water vapor.

A comprehensive study of the humidity measurement system is being conducted by Arnold Wexler, Chief of the Humidity Section in the Mechanics Division at NBS.

Wyllie, L. A., Jr., Wright, R. N., Sozen, M. A., Degenkolb, H. J., Steinbrugge, K. V., Kramer, S., **Effects on structures of the Managua earthquake of December 23, 1972,** *Bull. Seismol. Soc. Amer.* **64,** No. 4, 1069-1133 (Aug. 1974).

Key words: building; codes; earthquake damage; earthquakes; hazards; hospital; natural disasters; seismic; structural engineering.

The December 23, 1972, earthquake in Managua, Nicaragua caused extensive damage to structures throughout the city of Managua. There was damage to virtually every building in Managua, a city of approximately 400,000 inhabitants. An estimated 10,000 people were killed, mostly in the collapse of homes built of native taquezal construction. The city contained numerous reinforced concrete structures designed to recent standards. Although many of these buildings were heavily damaged, with some collapses, some had only minor damage. There were also several structures of structural steel.

The paper provides an overview of structural effects and discusses the performance of selected buildings in Managua illustrating the range of performance of modern construction. Damage to numerous other buildings will be discussed. The paper, while emphasizing the structural effects on buildings, also discusses the performance of non-structural elements, mechanical equipment, etc.

Zapf, T. L., **Calibration of quartz transducers as ultrasonic power standards by an electrical method,** *Proc. 1974 Ultrasonics Symp., Milwaukee, Wisconsin, Nov. 11-14, 1974, IEEE Cat. No. 74 CHO 896-ISU,* pp. 45-50 (IEEE, Inc., New York, N.Y., 1974).

Key words: piezoelectric transducers; standards of ultrasonic power; ultrasonic power; ultrasonic transducers.

Ultrasonic beam power from specially-designed quartz piston transducers can be determined from an appropriate set of electrical measurements. The characterized transducers can be used as transportable standards of ultrasonic power. A highly accurate twin-T null circuit is employed for the measurement of electrical conductances of half-wave resonant quartz transducers under certain loading conditions. This permits calculation of the equivalent resonant radiation conductance which, when multiplied by the square of the applied voltage, yields the emitted ultrasonic power into a load. Quartz transducers, thus characterized, can serve as standards of ultrasonic power for checking or calibrating ultrasonic power measuring equipment such as radiation force, calorimetric, and acousto-optic devices. With the equipment used at the National Bureau of Standards, uncertainties are estimated at less than ± 5 percent in the frequency range from 1 to 5 MHz.

Zhukov, V. V., Weisman, I. D., Bennett, L. H., **Nuclear magnetic resonance in cadmium alloys,** *J. Magn. Resonance* **16,** 29-34 (1974).

Key words: anisotropic Knight shift; Cd; Hg; isotropic Knight shift; Knight shift; Korringa product; nuclear magnetic resonance; spin lattice relaxation.

Experimental isotropic and anisotropic Knight shift data on ^{113}Cd and on ^{199}Hg in Cd-Hg alloys have been obtained between room and liquid-helium temperatures. The ^{113}Cd spin-lattice relaxation times in Cd and in a Cd + 10 at.% Hg alloy have also been measured at these temperatures. The Hg concentration dependence of the anisotropic

and isotropic Knight shifts at the ^{199}Hg site was found to be qualitatively similar to that of the corresponding shifts at the ^{113}Cd site. The Korringa relation for ^{113}Cd is obeyed, indicating that only one mechanism contributes to the Knight shift and spin-lattice relaxation. The ratio of isotropic Knight shifts, (Hg:Cd), extrapolated to zero Hg concentration, 4.67, is somewhat greater than the ratio, 3.69, of atomic hyperfine fields. This suggests that the amount of electronic "*s*" character at the Cd Fermi surface is anomalously low due to anisotropy effects and that adding Hg rapidly destroys the anisotropy by weakening and symmetrizing the lattice potential.

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